IEEE SMC **2016**

IEEE

2016 International Conference on Systems, Man, and Cybernetics

Workshop on Brain-Machine Interface Systems

October 8-12, 2016

Hotel Intercontinental

Budapest, Hungary

Sponsored by

IEEE SMC

Systems, Man, and Cybernetics Society

2016 IEEE International Conference on

Systems, Man, and Cybernetics

Workshop on Brain-Machine Interface Systems

WORKSHOP DIGEST

Welcome Message from the BMI Workshop Organizers

IEEE SMC 2016's 6th Workshop on Brain-Machine Interface Systems will be held October 8th-12th, 2016 in Budapest as part of the program of SMC 2016 - the flagship annual conference of the IEEE Systems, Man, and Cybernetics Society. This event will also host the second IEEE Brain Initiative Annual Meeting. The theme of this year's workshop, which involves the integration of Systems, Human-Machine Systems, and Cybernetics, is "New Research Opportunities and Industrial Applications in BMI Systems Arising from the IEEE Brain Initiative."

IEEE President and CEO Barry Shoop will open the BMI Workshop and give an invited talk on "Disruptive Innovations as a Vehicle to Develop Critical Thinking, Creativity and Innovation Skills".

We would like to welcome all SMC 2016 delegates who are either involved or interested in learning more about the state of the art and future challenges in BMI-related topics including sensor technologies, machine learning, big data, neurorehabilitation and standards to attend this workshop - which is offered free of charge.

The workshop is organized by the IEEE SMC Technical Committee on Brain-Machine Interfaces Systems and is technically co-sponsored by the IEEE Brain Initiative, IEEE Computational Intelligence Society, IEEE Consumer Electronic Society, IEEE Council on Electronic Design Automation, IEEE Engineering in Medicine and Biology Society, IEEE Magnetics Society, IEEE Robotics and Automation Society, IEEE Sensor Council, IEEE Signal Processing Society, IEEE Society on Social Implications of Technology, IEEE Solid-State Circuits Society, the IEEE Standards Association and the IEEE Systems Council.

The goal of the workshop is to facilitate the interaction and intellectual exchange between all researchers, developers and consumers of this technology. The latest advances, innovations, and applications will be presented. Topics such as decoding accuracy, task performance, human factors, decoding algorithms, and feedback represent both challenges to the field and a tremendous opportunity for collaborative and multidisciplinary research, involving not only peers with expertise in the field of BMI, but also expertise in systems engineering, human-machine systems, cybernetics, and/or other disciplines. The five-day workshop will feature multiple activities including tutorials, a special session on standards, three panels, a number of prominent invited speakers from industry and academia, presentations of contributed papers and a two-day Brain Computer Interface Hackathon.

A highlight of the workshop is a session on commercialization of technology held on October 10th, entitled "From Research to Scientific Breakthroughs to Improving the Lives of People: Four Unique Paths," with speakers Reese Jones, Founder Farallon, Netopia, BMUG; Joel Libove, Founder Furaxa, Ultraview; Stuart Mason Dambrot, Founder Transinopia, Critical Thought | TV; and Bernt R. Wahl, Founder Factle, Datahunt, Dynamic Software.

We are also pleased to have the following invited speakers:

- Jose Carmena (UC Berkeley), SMC 2016 keynote speaker: "Brain-machine interface systems: Learning to act in the cyber-physical world" held on October 10th
- José del R. Millán (EPFL): "Neuroprosthetics: The role of the brain's error monitoring system" held on October 10th
- Paul Sajda (Chair IEEE Brain Initiative; Columbia University): "Neural correlates of the "Aha" moment: Enabling brain-computer interfaces for labeling our environment" held on October 11th
- Andrew F. Laine (Columbia University; President EMBS): "Quantitative imaging informatics in cost effective PET imaging" held on October 12th

Moreover, there will be two focused special sessions. The IEEE Sensors Council has organized a special session with five prominent invited speakers who will talk on "Sensor Technologies for Multimodal Brain Interfacing" on October 12th. In addition, a full day special session focused on BMI and neurotechnology-related standards will take place on October 9th. This session, supported by the IEEE Standards Association, will discuss how

standardization of technologies such as BMI, Augmented Reality (AR)/Virtual Reality (VR), and other wearables, is needed to support integration and help accelerate the translation of these devices to commercialization.

The Brain Computer Interface Hackathon will be held on Saturday, October 8th and Sunday, October 9th. It is sponsored and organized by VSP, VSP the Shop, Vizzario, Qusp, IEEE Brain Initiative, and IEEE SMC Society. There are over $8,000 in prizes in cash and hardware prizes donated by the sponsors and organizers.

Two tutorials are held on the afternoon of Sunday, October 9th:

- Mobile BCI application: Neuroscience-based design and neurorehabilitation
- Why bother with advanced modeling in BCI? Lessons from neuroimaging

The workshop also features three panel sessions moderated by José del R. Millán (EPFL) and Jack Gallant (UC Berkeley):

- "Important Topics in Designing and Building Real World BMI: What is New?" held on October 10th
- "How Research and Methodologies in Systems, Human-Machine Systems, and Cybernetics can be applied to BMI" held on October 11th
- "What Have We Learned, Where Do We Go From Here?" held on October 12th

This year we also have 80 contributed papers. All of them were carefully peer-reviewed by at least two experts and will be published in the conference proceedings. The IEEE Brain Initiative Best Paper Award will be given to the best paper at this workshop, and five IEEE Brain Initiative student travel grants will be awarded. Besides this, all papers in the workshop will be eligible for SMC's Franklin V. Taylor Memorial Award and Best Student Paper Award. Contributions will be presented in technical sessions addressing a variety of topics including:

- Adaptive and self-calibrating BMI systems for independent use
- BMI for motor/cognitive rehabilitation and assistance and for neurodriving
- Brain and human-machine interaction
- Health and non-invasive wearable BMI
- Machine learning methods for brain-computer interfacing
- Multi-modal brain computer Interface and physiological computing
- Neuroscience based design: fundamentals and applications
- Neurostimulation and BMI
- Performance metrics and human factors for BMI training and operation
- Real world applications of brain computer interface systems
- Recent advances in BMI Speller
- Sensor systems for BMI and prosthetics

Finally, we would like to thank all the organizations and individuals who worked hard in organizing this Workshop. We especially thank the IEEE Brain Initiative for their generous funding and support of this workshop. We also thank the Brain Computer Interface Hackathon supporters: IEEE SMC Society and the IEEE Brain Initiative (sponsors, prizes, and funding), Vizzario (organizer, management, equipment, funding and prizes), Qusp (management, equipment, and prizes), Hardware/software manufacturers: (equipment and funding) Gtec, VSP the Shop, and Interaxon; (hardware) Brain Rhythm Inc., Cognionics, Emotiv, InteraXon, NCU, Neuroelectrics, NeuroSky, OpenBCI, Wearable Sensing, Thalmic Myo, Oculus Rift, HTC Vive, and DBglove.

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Brain Computer Interface Hackathon

A gathering such as IEEE SMC 2016 brings together great minds. We invite you to be a part of the Brain Hackathon, where participants are engaged in a brainstorming and collaborative round-the-clock marathon, designed to rapidly produce working prototypes. The goal of this particular Brain Hackathon is to stretch the boundaries of Brain Computer Interface (BCI) technology, to put creative minds from many disciplines together, and to provide an environment for innovation, entrepreneurship, and creation of applications/products that have great potential for commercialization. Participants will have the opportunity to participate in a number of challenges. Cost to participate is **FREE**.

Over $8,000 in cash and hardware prizes, including at least $5,000 in Vizzario/VSP Brain Hackathon Prizes, a $1,000 IEEE Brain Initiative Brain Hackathon Prize, a $1,000 IEEE SMC Brain Hackathon Prize, and a $1,000 Qusp Prize will be awarded. Individual or team participants (each up to 5 persons) are welcome, with a limitation of 130 individuals/26 teams. IEEE members will be given priority. See: https://abc-accelerator.com/budapest-hackathon-learn-more-page/.

Preliminary Schedule	
October 8, 2016	
9:00	Introduction, overview, industry talk, group formation, general rules and guidelines, choosing topic of work, starting preparation work
11:00	Submission of Project Title and start of work
12:00	Lunch Break (1 hour)
16:00	Jury making rounds (checking teams' progress, approx. 5 min per team)
18:00	Dinner Break (1 hour)
22:00	Jury making rounds (checking teams' progress, approx. 5 min per team)
00:00	Midnight Break (1 hour)
October 9, 2016	
8:00	Breakfast Break (1 hour)
10:00	Jury making rounds (checking teams' progress, approx. 5 min per team)
12:00	Lunch Break (1 hour)
13:00	Jury making rounds (checking teams' progress, approx. 5 min per team)
14:00	Project Submission, followed by Project Demos and Jury Evaluation
15:30	Awards Presentation
16:00	Hackathon ends
18:30	Selected winners have projects on display/demos at SMC reception
October 10, 2016	
13:00 – 18:30	Selected winners have projects on display/demos at SMC BMI Workshop

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October 8 (Saturday), 09:00-18:00, InterContinental Budapest, Ballroom II
October 9 (Sunday), 09:00-16:00, InterContinental Budapest, Ballroom II

BMI Standards Session

October 9 (Sunday), 08:30-17:00, InterContinental Budapest, Ballroom III and panorama I

The SMC 2016 provides an international forum for researchers and practitioners to report up-to-the-minute innovations and exchange ideas and advances in all aspects of systems science and engineering, human machine systems, and cybernetics.

During this session on BMI-related standards, organized by the **IEEE Standards Association**, the use of neurotechnologies for invasive and non-invasive practices will be discussed. How this technology is implemented for surgery, Augmented Reality (AR)/Virtual Reality (VR), or wearables, and how standardization of the technology is needed to support integration and help accelerate the translation of these devices to commercialization. This session is open to the attendants to IEEE SMC conference.

Topics to be discussed:

- What is a BMI standard?
- Should there be a separate set of standards for clinical and non-clinical applications?
- What would a framework for standards on diverse topics, plus their interoperability look like?
- What are the biggest challenges to using these technologies?
- What are the highest priorities or the biggest challenges that can be addressed by standards?
- What needs be addressed in the next 3 years?
- Is there a need for standards on the reliability of these systems in terms of performance?
- Should standards be set to protect from third-party access?
- Is it the role of standards to define which information should or should not be stored? Or whether encryption/anonymization is required.

This session will be composed of short presentations and panels with different stakeholders from the private, academic, and regulatory sectors. Ample time has been reserved for discussions with contributions from the attendants, including breakout discussion sessions on standards gaps for clinical and non-clinical BMI applications. Plenary sessions will take place on the Ballroom III. Breakout roundtables (15:00-16:30) will take place in the Ballroom III and Panorama I.

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The outcome of this workshop will be used to drive establishment of the standards committee on Neurotechnologies.

http://go.epfl.ch/smc2016_bmi_standards
http://standards.ieee.org

Program: Special Session on Standards

9:00 AM **Ballroom III**	**Welcome: Michael H. Smith, Chair SMC2016 BMI Workshop** **Opening Remarks and Moderation: Ricardo Chavarriaga (EPFL)**
9:15 – 10:30 **Ballroom III**	Signal acquisition and stimulation - **Panel I** Aureli Soria-Frisch, Neuroelectrics Barcelona, Starlabs, Spain Christoph Guger/Francisco Fernandes, g.Tec, Austria Brain, Behavior and AR/VR – **Panel II** • Gangadhar Garipelli (TBD), Mindmaze, Switzerland • Khizer Kaderi/Mohan Reddy, Vizzario/VSP, USA
10:30 – 10:45	**Break**
10:45 – 12:00 **Ballroom III**	Data analysis and sharing - **Panel III** • Tim Mullen, Qusp, USA • Louis Mayaud, Mensia Technologies, France BMI evaluation with end-users – **Panel IV** • José Contreras-Vidal, U Houston, USA • Reinhold Scherer, TU Graz, Austria
12:00 – 13:00	**Lunch**
13:00 – 14:30 **Ballroom III**	**Why do standards Matter? Moderator Bill Ash (IEEE Standards)** • Carole Carey – Standards & Brain Initiative overview • Hasan Ayaz – Brain, Behavior and AR/VR • May Wang – Needs and gaps in standards • Felipe Aguel, NIH/NINDS - Why standards are needed in medical devices • Walter Besio – EEG, sensors and signal processing
14:30 – 15:15 **Panorama I** **Ballroom III**	**Roundtable discussion: Wearables, fMRI, MEG, Invasive and Non-Invasive technologies** BMI systems are composed of several interconnected devices (e.g., EEG acquisition, AR/VR headsets, etc.) • Clinical and Non-clinical applications • How should BMI-related standards address the interoperability of these (heterogeneous) devices? • How are technologies that are different able to be integrated? Current data formats (e.g., EDF) were conceived for storing data in “open loop” settings. Is there a need to set standards on how to store and share the information gathered during BMI experiments and operations?
15:15 – 15:30	**Break**
15:30 – 16:00 **Panorama I** **Ballroom III**	**Roundtable discussion: Wrap up and readout preparation**
16:00 – 16:30 **Panorama I**	**Readouts from the roundtables**
16:30 – 17:00 **Panorama I**	**Wrap up**

From Research to Scientific Breakthroughs to Improving the Lives of People: Four Unique Paths

Organizer: Bernt Wahl, Chair: Michael H. Smith
October 10 (Monday), InterContinental Budapest, 16:15-18:30, Ballroom II-III

Reese Jones
Founder: Farallon, Netopia, BMUG

Joel Libove
Founder: Furaxa, Ultraview

Stuart M. Dambrot
Founder: Critical Thought|TV

Bernt R. Wahl
Founder: Factle, Datahunt, Dynamic Software

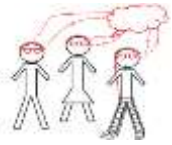
How do scientific breakthrough technologies go from a simple idea, to a few research prototypes costing millions, to products produced in the millions costing consumers/users only hundreds? Can we replace confining multi-ton, multi-million dollar fMRI machines with helmets weighing less than the brains they are imaging? Can we stream brain activity from billions of people and feed it in meaningful and selectively tailored ways to others, enabling global collaboration in an augmented environment?

What does it take to create, invent, and develop revolutionary new technologies that most cannot even envision? Some factors behind scientific breakthroughs are:

- A burning need and passion to see a longstanding problem solved.
- A wide breadth of expertise in the founder and colleagues, crossing multiple disciplines, are needed to devise a viable solution – often where others have failed.
- The tenacity to stick with a tortuous development path riddled with technical challenges, naysayers, lack of capital and other resources, regulatory issues, etc.
- The ability to quickly alter course along the way, as well as knowing when to stay the course despite overwhelming difficulties!
- Creativity - the gift of being able to visualize and analyze problems in unconventional ways. May be enhanced through exposure to external stimuli, such as art, listening to or playing music, hiking in nature and conversing and collaborating with others.
- A creative and dedicated team given the freedom to invent and take risks, tempered with guidance and encouragement from the founder.
- The ability to recognize when research results become sufficiently significant and mature to be developed into a product, and when they are not.

In this session, founders from companies collectively worth over $5 billon will share tales of pathways from research ideas to scientific breakthroughs to consumer/user products - how they went from identifying and finding solutions to scientific problems, ascertaining/recognizing/discovering customers, and building their enterprise using various models including:

- Grow as you go – letting early customers finance development
- Partner(s), consortia and virtual corporations
- Leveraging existing technologies to develop new products
- Licensing out technologies to provide revenue
- Raising investment capital



From a founder who repurposed ICs developed for defense to enable a wearable brain imager that unexpectedly shows promise for functional brain imaging, to another founder who used the power of computing to visualize chaos mathematics, to another who created high level security for mobile platforms, and finally, to another who analyzes deep-structure conceptual and neural connections between multiple areas of knowledge and creativity; each story will be exciting and unique.

Four such scientific product genesis successes, some carefully planned, others serendipitous, but all with the potential to help mankind, are briefly presented by the founders who helped make them happen.

Second IEEE Brain Initiative Meeting Held During SMC 2016 BMI Workshop

October 11 (Tuesday), 14:00-15:30, InterContinental Budapest, Ballroom I
Chair: Paul Sajda, Co-Chair: Jose Carmena

The IEEE Brain Initiative [brain.ieee.org] was launched with the mission to facilitate cross-disciplinary collaboration and coordination to advance research, standardization and development of technologies in neuroscience to help improve the human condition. After the success of the first IEEE Brain Initiative Meeting which took place December 2015 at Columbia University, we invite you to participate in the second IEEE Brain Initiative Meeting, where you will hear about the *latest brain research and developments from various IEEE Societies and Councils involved in this initiative, and be a part of the strategic discussion to plan for new endeavors and identify new opportunities.*

It is free to attend the IEEE Brain Initiative Meeting, which is held during the SMC 2016 BMI Workshop. We highly encourage participants to the IEEE Brain Initiative Meeting to also register and attend the SMC 2016 BMI Workshop. The IEEE Brain Initiative is a technical co-sponsor of this Workshop, along with eleven (11) IEEE Societies and Councils and the IEEE Standards Association.

Chair, Paul Sajda, Ph.D., Columbia University
Co-Chair, Jose Carmena, Ph.D., University of California, Berkeley
Senior Advisor, Metin Akay, Ph.D., University of Houston
Senior Advisor, Michael H. Smith, Ph.D., University of California, Berkeley

BMI Workshop Schedule

	9:00 - 18:00							
8th October Satur-day	**Brain Computer Interface Hackathon** Room: Ballroom II							
	9:00 – 9:15	9:15 - 10:30	9:15 - 10:30	10:45 - 12:00	10:45 - 12:00	13:00 - 14:30	14:30 – 16:00	16:00 - 17:00
9th October Sunday	**BMI Standards Session, Opening Remarks: Michael H. Smith** Room: Ballroom III	**BMI Standards Session Panel I:** "Signal Acquisition and Stimulation" Room: Ballroom III	**BMI Standards Session Panel II:** "Brain, Behavior and AR/VR" Room: Ballroom III	**BMI Standards Session Panel III:** "Data Analysis and Sharing" Room: Ballroom III	**BMI Standards Session Closing Panel IV:** "BMI Evaluation with End-Users" Room: Ballroom III	**BMI Standards Session Discussion:** "Why do Standards Matter?" Room: Ballroom III	**BMI Standards Session Roundtable Discussion** Room: Panorama I Ballroom III	**BMI Standards Session Readouts from the Roundtables and Wrap up** Room: Panorama I
	9:00 - 16:00			13:30 - 15:00			15:30 - 17:00	
	Brain Computer Interface Hackathon Room: Ballroom II			**Tutorial I:** "Mobile BCI Application: Neuroscience-Based Design and Neurorehabilitation" Room: Duna Salon II			**Tutorial II:** "Why Bother with Advanced Modeling in BCI? Lessons from Neuroimaging" Room: Duna Salon II	
	13:30 - 14:15	14:15 - 15:00		15:30 - 16:15		16:15 - 17:00	17:00 - 18:30	
10th October Monday	**BMI Opening Session: Barry L. Shoop 2016 IEEE President and CEO** "Disruptive Innovations as a Vehicle to Develop Critical Thinking, Creativity and Innovation Skills" Room: Ballroom II-III	**Panel I:** "Important Topics in Designing and Building Real World BMI Systems: What is New?" Room: Ballroom II-III		**Invited Lecture I:** "Neuroprosthetics: The Role of the Brain's Error Monitoring System" **José del R. Millán** Room: Ballroom II-III		**Founders Keynote Session I:** "From Research to Scientific Breakthroughs to Improving the Lives of People: Four Unique Paths" Room: Ballroom II-III	**Founders Keynote Session II:** "From Research to Scientific Breakthroughs to Improving the Lives of People: Four Unique Paths" Room: Ballroom II-III	
	9:30 - 11:00				11:00 - 11:45	11:45 - 12:30	14:00 - 15:30	
11th October Tuesday	**BMI-I** "Performance Metrics and Human Factors for BMI Training and Operation" Room: Panorama I	**BMI-II** "Adaptive and self-calibrating BMI systems for independent use" Room: Panorama V		**BMI-III** "Health and Non-Invasive Wearable BMI" Room: Ballroom I	**Invited Lecture II:** "Neural Correlates of the "Aha" Moment: Enabling Brain-Computer Interfaces for Labeling our Environment" **Paul F. Sajda** Room: Ballroom I	**Panel II:** "How Research and Methodologies in Systems, Human-Machine Systems, and Cybernetics can be Applied to BMI" Room: Ballroom I	**IEEE Brain Initiative Meeting** (open to all) Room: Ballroom I	
	9:30 - 11:00							
12th October Wednes-day	**BMI-IV** "Real World Applications of Brain Computer Interface Systems I" Room: Panorama I	**BMI-V** "BMI for Motor/Cognitive Rehabilitation and Assistance I" Room: Panorama V		**BMI-VI** "Neuroscience Based Design: Fundamentals and Applications" Room: Duna Salon II	**BMI-VII** "BMI for Neurodriving" Room: Ballroom I	**BMI-VIII** "Machine Learning Methods for Brain-Computer Interfacing I" Room: Bellevue 2	**BMI-IX** "Neurostimulation and BMI" Room: Bellevue 3	
	11:00 - 12:30							
	BMI-X "Real World Applications of Brain Computer Interface Systems II" Room: Panorama I	**BMI-XI** "BMI for Motor/Cognitive Rehabilitation and Assistance II" Room: Panorama V		**BMI-XII** "Multi-Modal Brain Computer Interface and Physiological Computing" Room: Ballroom I	**BMI-XIII** "Brain and Human-Machine Interaction" ---------- "A Tribute to Walter J. Freeman" Room: Ballroom II	**BMI-XIV** "Machine Learning Methods for Brain-Computer Interfacing II" Room: Bellevue 2	**BMI-XV** "Sensor Systems for BMI and Prosthetics" Room: Bellevue 3	
	14:00 - 15:30							
	BMI-XVI "Real World Applications of Brain Computer Interface Systems III" Room: Panorama I			**Invited Speakers (Sensors Council):** "Sensor Technologies for Multimodal Brain Interfacing" Room: Ballroom I		**BMI-XVII** "Recent Advances in BMI Speller" Room: Ballroom II		
	16:00 - 16:45	16:45 - 17:30			17:30 - 18:15		18:15 - 19:00	
	Invited Lecture III: "Quantitative Imaging Informatics in Cost Effective PET Imaging" **Andrew F. Laine** Room: Ballroom I	**Panel III (part a)** "What Have We Learned, Where Do we Go From Here" Room: Ballroom I			**Panel III (part b)** "What Have We Learned, Where Do we Go From Here" Room: Ballroom I		"Strategic Roadmap Discussion for BMI: Audience Participation" Room: Ballroom I	

* Room Information:
- Hotel InterContinental: Ballroom, Panorama, Duna Salon
- Hotel Sofitel: Bellevue

BMI Workshop Panels

BMI Panel I

Important Topics in Designing and Building Real World BMI Control Systems: What is New?

October 10 (Monday), 14:15-15:00, InterContinental Budapest, Ballroom II-III

Abstract

The goal of this panel is to hear about the current challenges and hot topics in BMI research from experts on the design and use of BMI/BCI systems. By identifying the challenges confronting the successful clinical translation and commercial application of BMI/BCI systems in real-world situations, this panel should identify some opportunities for SMC and other efforts to dramatically improve BMI/BCI system performance and benefits for the patients and/or users.

Session Chair

Michael H. Smith (University of California, Berkeley)

Moderator

José del R. Millán (École Polytechnique Fédérale de Lausanne)

Panelists

Jan Rabaey (UC Berkeley), Jack Gallant (UC Berkeley), Jose Luis Contreras-Vidal (University of Houston, Tecnológico de Monterrey), Reinhold Scherer (Graz University of Technology), S. W. Lee (Korea University)

BMI Panel II

How Research and Methodologies in Systems, Human-Machine Systems, and Cybernetics can be applied to BMI Systems

October 11 (Tuesday), 11:45-12:30, InterContinental Budapest, Ballroom I

Abstract

The goal of this panel is to engage leading researchers within SMC and elsewhere to discuss exploring various topics that are relevant to the development of robust and high-performance BMI systems, and to encourage the collaboration between researchers involved in BMI directly with those working in the domains of SMC and the IEEE Brain Initiative. We will also discuss whether and how SMC and IEEE Brain Initiative research lines and methodologies are becoming part of BMI.

Session Chair

Michael H. Smith (University of California, Berkeley)

Moderator

José del R. Millán (École Polytechnique Fédérale de Lausanne)

Panelists

Barry L. Shoop (IEEE President and CEO), Dimitar Filev (IEEE SMCS President), Ricardo Chavarriaga (SMC BMI TC), Paul Sajda (Chair, IEEE Brain Initiative), Andrew F. Laine (President, IEEE EMBS)

BMI Panel III
What Have We Learned, Where Do We Go From Here?

October 12 (Wednesday), 16:45-18:15, InterContinental Budapest, Ballroom I

Abstract

This is the final session of the workshop, in which the panelists and audience members share insights gained regarding the state-of-the-art BMI methods presented in this Workshop. Furthermore, modifications / updates to the set of relevant BMI-SMC metrics and a technology-development road map will also be discussed.

Session Chair

Michael H. Smith (University of California, Berkeley)

Moderator

Paul Sajda (Columbia University)

Panelists

Phillip Alvelda (DARPA program manager), Ricardo Chavarriaga (Center for Neuroprosthetics, EPFL), Vinod Prasad (Nanyang Technological University), Christoph Guger (CEO of g.tec), Dongrui Wu (CEO, DataNova), Joel Libove (CEO, Furaxa), Tim Mullen (CEO, Qusp), Fei-Yue Wang (Chinese Academy of Sciences), Gangadhar Garipelli (MindMaze).

Disruptive Innovations as a Vehicle to Develop Critical Thinking, Creativity and Innovation Skills

October 10 (Monday), 13:30-14:15, InterContinental Budapest, Ballroom II - III

Barry L. Shoop
2016 IEEE President and CEO
Professor and Department Head
Department of Electrical Engineering and Computer Science
U.S. Military Academy
West Point, New York, USA

Abstract

A desirable goal of engineering education is to teach students how to think critically and be creative and innovative. However, the speed of technological innovation and the continual expansion of disciplinary knowledge leave little time in the curriculum for students to formally study innovation, particularly at the undergraduate level. We have developed a novel upper-division interdisciplinary undergraduate engineering course that delivers disruptive and innovative applications of commercial technologies to an external funding agency and simultaneously develops the critical thinking, creativity, and innovation of these students. The course is structured as a deliberate interactive engagement between students and faculty that employs the Socratic Method to develop an understanding of disruptive and innovative technologies and a historical context of how social, cultural, and religious factors impact the acceptance or rejection of innovation. The course begins by developing the background understanding of what disruptive technology is and a historical context about successes and failures of social, cultural, and religious acceptance of technological innovation. To develop this framework, students read *The Innovator's Dilemma* by Clayton M. Christensen, *The Structure of Scientific Revolutions* by Thomas S. Kuhn, *The Discoverers* by Daniel J. Boorstin, and *The Two Cultures* by C.P. Snow. For each class meeting, students survey current scientific and technical literature and come prepared to discuss current events related to technological innovation. Each student researches potential disruptive technologies and prepares a compelling argument of why the specific technologies are disruptive so they can defend their choice and rationale. During course meetings students discuss the readings and specific technologies found during their independent research. As part of this research, each student has the opportunity to interview forward thinking technology leaders in their respective fields of interest. In this presentation we will describe the course and highlight the results from teaching this course over the past eight years.

Biography

Barry L. Shoop is Professor of Electrical Engineering and Head of the Department of Electrical Engineering and Computer Science at the United States Military Academy at West Point. In this role, he is responsible for an undergraduate academic department with over 79 faculty and staff supporting ABET accredited programs in electrical engineering, computer science, and information technology and serving over 2300 students annually. During his tenure at West Point, he has served in a number of leadership positions including Director of the Electrical Engineering Program and Director of the Photonics Research Center. Earlier in his career, he was a satellite communication engineer responsible for the design and installation of a high capacity, global digital communication network, and the CTO for a US$4.5B organization addressing the Improvised Explosive Device (IED) challenge worldwide. Barry received the Ph.D. from Stanford University and B.S. from the Pennsylvania State University, both in electrical engineering. He is a Fellow of the IEEE, the Optical Society of America (OSA), and the International Society for Optical Engineering (SPIE), and a member of Phi Kappa Phi, Eta Kappa Nu, and Sigma Xi. In 2008, OSA recognized Barry with their Robert E. Hopkins Leadership Award, and in 2013 he earned

both the SPIE Educator Award and the IEEE Haraden Pratt Award. He holds a patent on photonic analog-to-digital conversion and has authored over 150 archival publications as well as eight books and book chapters. He is a licensed Professional Engineer in Virginia, USA.

From Research to Scientific Breakthroughs to Improving the Lives of People: Four Unique Paths

Organizer: Bernt R. Wahl
Chair: Michael H. Smith
October 10 (Monday), InterContinental Budapest, 16:15-18:30, Ballroom II-III

BMI and Brain Imaging: Gateways to Brain-Body-Internet Convergence

Reese Jones
Founder: Farallon, Netopia, BMUG

Abstract

Like a mirror, the Internet is already a reflection of who we are and how others perceive us, like our internet digital twin or an extension of our biology. From a lifetime of credit reports to medical records, from social media to recorded phone conversations, the Internet may know more about us than we know about ourselves. Today's renaissance includes our Internet twin – and to be self-aware, we must also know and care for our digital self as part of our mind, body and spirit. Brain computer interfaces are as simple as keyboards, screens, and phones. Brain imaging technologies, and more abundant, myriad, and sophisticated sensors, are exponentially enhancing the commingling of brain, body and Internet.

Biography

Reese Jones is a biophysicist, inventor and entrepreneur. He has contributed to the IPOs, acquisitions and growth of over a dozen startups, including Farallon, Netopia, Smaato, Genome Compiler, Cambrian Genomics, and Singularity University at NASA Research Park in Silicon Valley. Reese has served on boards at Santa Fe Institute, Harvard Medical School's Genetics Council, and Singularity University.

Transforming a High-Risk Idea into a Prototype

Joel Libove
Founder: Furaxa, Ultraview

Abstract

Bringing a useful but risky new technology to life can be a decade-long R&D effort that requires extreme perseverance, unconventional funding, piggybacking, and collaborative strategies, for what. VCs and other equity funders, and agencies like NIH and NSF, may not have the needed patience and risk tolerance, often wanting an idea to be proven before they will fund it. Nevertheless, interim revenue and crucial intellectual partnering can be obtained by selling elements of a new technology into non-competing defense, education and commercial applications. This presentation will describe how new IC architectures and data acquisition boards we developed for immediate military markets are now forming the basis for a wearable picosecond-pulse-based brain imager prototype. The same tiny 1.5cm^2 antenna/radar-IC assemblies designed for short-range radar can be arrayed to create rudimentary readings of real-time vascular and probable neural activity in the brain. Preliminary operating results will be presented, along with a roadmap for achieving a usable spatial image and ultimately creating a wearable 2Kg, low-cost, real-time internet-connected functional BMI/neuroimaging helmet for clinical and operational environments. Potential futuristic applications not possible with fMRI will also be proposed.

Biography

Joel Libove specializes in analog and microwave electronics, MMIC design, picosecond amplifiers, pulse generators and samplers and high dynamic range data acquisition systems. He is founder and president of Furaxa, Inc., where he leads development of a wearable radar-based helmet system for real-time brain imaging.

Libove is also chairman of Ultraview Corp, where he designed real-time parallel VMEbus and PCIbus protocol and timing violation analyzers, which won three industry awards and were used by hundreds of government agencies and corporations. He also led design of six generations of high speed data acquisition boards, with zero-dead-time hardware averaging. These boards are used in military, R&D and medical applications. A 16-channel Ultraview imager-on-a-board is used in the Furaxa imaging helmets.

Joel has 13 patents and one patent pending. He received a Ph.D. and MSEE in engineering from University of California, Berkeley, and a BSEE from Cornell University.

Beyond Innovation: Imagination, Intuition and Insight

Stuart Mason Dambrot
Founder: Critical Thought|TV

Abstract

Innovation – the action or process of creating a novel method, product or idea – requires a number of key factors to be successful. Those factors typically mentioned include passion, expertise, tenacity, flexibility, and creativity. That being said, however, not only are there two types of innovation – that is, sustaining and disruptive – but there are a number of critical factors associated with the latter, these being imagination, intuition and Insight. This presentation will focus on disruptive innovation and the often downplayed value of these three related factors in the successful creation, development and adoption of breakthrough near-and medium-term future technologies that are not yet possible. In addition, examples of renowned scientists and other individuals who have taken this approach to deliver world-changing innovations will be cited.

Biography

Stuart analyzes deep-structure conceptual and neural connections between multiple areas of knowledge and creativity, synthesizes convergent and emergent trends in a wide range of research disciplines, envisions long-term future scenarios, and creates probabilistic pathways to arrive at or avoid these scenarios. His primary interest is evolutionary neurobiology within a technological and sociocultural context. Stuart is giving a talk on Exocortical Cognition at SMC 2016, and as an invited speaker and panelist has spoken about Augmented Cognition, Synthetic Biology, Philosophy of Science, Sociopolitical Futures, Post-Scarcity Economics, and other topics at New York Academy of Sciences, Cooper-Union, World Technology Summit, Science House, and other venues. His publications include *The Zeitgeist of Change: The evolutionary neurobiology of political behavior* and *Of Mind and Money: Post-scarcity economics and human nature*, and has contributed to *IEEE Spectrum, Nature, Science, Nature Biotechnology, Scientific American, Photonics Spectra, New Scientist, Chemical Week, Electronics, Electronic Engineering Times, Japan Times, 01 Informatique, Economist, International Herald Tribune, Financial Times, InfoWorld, Managing Automation, Asian Venture Capital Journal*, and other journals and publications.

Discovery's Uncertain Paths to Success

Bernt R. Wahl
Founder and Director, Brain Machine Interface Consortium
Founder: Factle, Datahunt, Dynamic Software

Abstract

A combination of many elements (technological breakthroughs, market adaptations, strong innovation teams, sufficient resource allocation) determines whether innovation is successful when they interact in a new and effective manner with appropriate timing and convergent creation of a product market. The speaker will discuss life events that helped him navigate through five technology revolutions – Personal Computers, Chaos Theory, the Internet, Big Data/Machine Learning and Brain-Machine Interfaces – each time building on prior experience to lay the foundation for yet unproven future ideas. He will share insights learned from personal knowledge (including stories from his years of teaching entrepreneurship to over 2,000 engineering students all over the world) as well as methods learned from fellow innovators, these encompassing some of Silicon Valley's foremost pioneers as well as a new generation of innovators.

Biography

Bernt Rainer Wahl is a mathematician, mentor, entrepreneur, author, and. currently a founder and director of Brain Machine Interface Consortium. He has served as CEO of Factle Corporation, Datahunt, and Dynamic Software, and is a former UC Berkeley faculty member. Wahl teaches entrepreneurship and engineering around the world, served as an Industry Fellow at the Center of Entrepreneurship and Technology, was Executive in Residence at the Skydeck, and in 2002 was awarded a Fulbright Fellowship to Malaysia. He was an early pioneer in the fields of chaos and fractal geometry, authoring Exploring Fractals (1994) and co-authoring The Fractal Explorer (1991). His first company was in mathematical visualization at Dynamic Software, which he co-founded with Peter Van Roy in 1987, where his work was showcased in the fashion industry, including the work of designer Jhane Barnes and was featured on the cover of Apple's site.

In 2001, Bernt Wahl led the management buyout attempt of the search engine company Infoseek through the firm Datahunt. In 2002 he started Factle, a search engine focused on specialized search and local demographics. Wahl worked for United Nations on ecotourism and helped the U.S. National Park Service build its first website. He is also involved in social causes, including the work done by The International Justice Mission, and various other organizations' work on the global dissemination of information.

Advances in Brain-Machine Interface Systems

October 10 (Monday), 11:00-12:00, InterContinental Budapest, Ballroom I-III

Jose M. Carmena
Helen Wills Neuroscience Institute
Department of Electrical Engineering and Computer Sciences
UC Berkeley, USA

Abstract

Brain-machine interfaces (BMIs) is a novel technology that holds great potential to aid large numbers of people with sensory, motor and cognitive disabilities. BMIs provide also a framework for examining basic neuroscience questions, especially those related to the understanding of how neural plasticity relates to the acquisition and consolidation of neuroprosthetic skills, i.e. accurate, readily-recalled control of disembodied actuators irrespective of natural physical movement. In this talk I will postulate that achieving skillful, natural control of a multi-degree-of-freedom prosthetic device will entail synergizing two different types of adaptation processes: natural (brain plasticity) and artificial (decoder adaptation), as well as providing realistic sensory feedback from the prosthetic device. I will present recent work from our laboratory showing that 1) neuroplasticity facilitates consolidation of neuroprosthetic motor skill in a way that resembles that of natural motor learning; 2) corticostriatal plasticity is necessary for neuroprosthetic skill learning, and 3) closed-loop decoder adaptation (CLDA) techniques can expedite the learning process by adapting the decoder parameters during closed-loop BMI operation (i.e., while the subject is using the BMI). We believe that BMI systems capable of exploiting both neuroplasticity and CLDA will be able to boost learning, generalize well to novel movements and environments, and ultimately achieve a level of control and dexterity comparable to that of natural arm movements.

Short Biography

Jose M. Carmena is Professor of Electrical Engineering and Neuroscience at the University of California-Berkeley, and Co-Director of the Center for Neural Engineering and Prostheses at UC Berkeley and UCSF. His research program in neural engineering and systems neuroscience is aimed at understanding the neural basis of sensorimotor learning and control, and at building the science and engineering base that will allow the creation of reliable neuroprosthetic systems for the severely disabled. Dr. Carmena received the B.S. and M.S. degrees in electrical engineering from the Polytechnic University of Valencia (Spain) in 1995 and the University of Valencia (Spain) in 1997. Following those he received the M.S. degree in artificial intelligence and the Ph.D. degree in robotics both from the University of Edinburgh (Scotland, UK) in 1998 and 2002 respectively. From 2002 to 2005 he was a Postdoctoral Fellow at the Department of Neurobiology and the Center for Neuroengineering at Duke University (Durham, NC). He is senior member of the IEEE (RA, SMC and EMB societies), Society for Neuroscience, and the Neural Control of Movement Society. Dr. Carmena has been the recipient of the Bakar Fellowship (2012), the IEEE Engineering in Medicine and Biology Society Early Career Achievement Award (2011), the Aspen Brain Forum Prize in Neurotechnology (2010), the National Science Foundation CAREER Award (2010), the Alfred P. Sloan Research Fellowship (2009), the Okawa Foundation Research Grant Award (2007), the UC Berkeley Hellman Faculty Award (2007), and the Christopher Reeve Paralysis Foundation Postdoctoral Fellowship (2003). More information of Prof. Carmena can be found: http://www.eecs.berkeley.edu/~carmena.

Neuroprosthetics: The Role of the Brain's Error Monitoring System

October 10 (Monday), 15:30-16:15, InterContinental Budapest, Ballroom II-III

José del R. Millán
Defitech Foundation Chair in Brain-Machine Interface
Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

Abstract

Future neuroprosthetics will be tightly coupled with the user in such a way that the resulting system can replace and restore impaired upper limb functions because controlled by the same neural signals than their natural counterparts. This means that, as in natural motor control, goal-directed behavior is dynamically modulated by perceptual feedback resulting from executed actions. Current brain-computer interfaces (BCI) partly emulate human motor control as they decode cortical correlates of movement parameters—from onset of a movement to directions to instantaneous velocity—in order to generate the sequence of movements for the neuroprosthesis. A closer look, though, shows that goal-oriented motor control also incorporates the output of cognitive processes that dynamically modulate volitional interaction. A prominent example of such a kind of perceptual cognitive process is error monitoring. In this talk I will describe recent progress in our lab on decoding error-related brain potentials in a variety of paradigms, including novel BCI paradigms and continuous motor actions.

Biography

Dr. José del R. Millán joined the École Polytechnique Fédérale de Lausanne (EPFL) in 2009 as the first professor of the Center for Neuroprosthetics where he holds the Defitech Foundation Chair. He received a PhD in computer science from the Technical University of Catalonia, Barcelona, in 1992. Previously, he was a research scientist at the Joint Research Centre of the European Commission in Ispra (Italy), a senior researcher at the Idiap Research Institute in Martigny (Switzerland). He has also been a visiting scholar at the Universities of Stanford and Berkeley as well as at the International Computer Science Institute in Berkeley.

Dr. Millán has made several seminal contributions to the field of brain-computer interfaces (BCI), especially based on electroencephalogram (EEG) signals. Most of his achievements revolve around the design of brain-controlled robots. He puts a strong emphasis on the use of statistical machine learning techniques so as to achieve a seamless coupling between the user and the brain-controlled device. A key element is the design of efficient and robust algorithms for real-time decoding of patterns of brain activity associated to different aspects of voluntary behaviour. He also builds on neuroscience findings to design new interaction protocols to operate complex devices. During the last years he is prioritizing the translation of BCI to end-users suffering from motor disabilities. In parallel, he is designing BCI technology to offer new interaction modalities for able-bodied people.

Neural Correlates of the "Aha" Moment: Enabling Brain-Computer Interfaces for Labeling Our Environment

October 11 (Tuesday), 11:00-11:45, InterContinental Budapest, Ballroom I

Paul Sajda
Departments of Biomedical Engineering,
Electrical Engineering and Radiology
Columbia University

Abstract

As we move through an environment, we are constantly making assessments, judgments, and decisions about the things we encounter. Some are acted upon immediately, but many more become mental notes or fleeting impressions — our implicit "labeling" of the world. In this talk I will describe our work using physiological correlates of this labeling to construct a hybrid brain-computer interface (hBCI) system or augmented navigation in a simulated 3-D environment. Specifically, we record electroencephalographic (EEG), saccadic, and pupillary data from subjects as they move through a small part of a 3-D virtual city under free-viewing conditions. Using machine learning, we integrate the neural and ocular signals evoked by the objects they encounter to infer which ones are of subjective interest. These inferred labels are propagated through a large computer vision graph of objects in the city, using semi-supervised learning to identify other, unseen objects that are visually similar to those that are labelled. Finally, the system plots an efficient route so that subjects visit similar objects of interest. We show that by exploiting the subjects' implicit labeling, the median search precision is increased from 25% to 97%, and the median subject need only travel 40% of the distance to see 84% of the objects of interest. We also find that the neural and ocular signals contribute in a complementary fashion to the classifiers' inference of subjects 'implicit labeling. In summary, we show that neural and ocular signals reflecting subjective assessment of objects in a 3-D environment can be adaptively integrated with models of that environment, resulting in an hBCI system that improves navigation and information delivery specific to the user's interests.

Biography

Paul Sajda is a professor in the Departments of Biomedical Engineering, Electrical Engineering and Radiology at Columbia University and Director of the Laboratory for Intelligent Imaging and Neural Computing at Columbia University. Much of his current research focuses on using multimodal neuroimaging and behavioral measures to track selective attention and the dynamics of cognitive state during rapid decision making. He also applies these basic scientific findings to engineer neurotechnology systems that improve human-machine interaction. He is a Fellow of the IEEE, Editor-in-Chief of IEEE Transactions on Neural Systems and Rehabilitation and Chair of the IEEE Brain Initiative. Contact him at psajda@columbia.edu.

Quantitative Imaging Informatics in Cost Effective PET Imaging

October 12 (Wednesday), 16:00-16:45, InterContinental Budapest, Ballroom I

Andrew F. Laine, D. Sc.
Percy K. and Vida L.W. Hudson Professor of Biomedical Engineering
Professor of Radiology (Physics), Department of Radiology
Chair, Department of Biomedical Engineering
Director, Heffner Biomedical Imaging Laboratory, Columbia University, New York, NY, USA

Abstract

An important tool for studying brain disorders is positron emission tomography (PET), a nuclear imaging technology that allows for the in vivo functional characterization and quantification of blood flow, metabolism, protein distribution, and drug occupancy using radioactively tagged probes (tracers). Full quantification of PET images requires invasive arterial input function (AIF) measurement through online arterial blood sampling for the duration of the scan (1-2 hours). The AIF is used to correct images by accounting for the tracer bioavailability, which depends on an individual's physiological capacity for clearance, distribution and metabolism of the tracer. However, AIF measurement is invasive, risky, time consuming, uncomfortable for patients, and costly. Perhaps most importantly, it is impractical at the point-of-care and therefore limits clinical utility of PET. We believe an integrative multi-modal approach is possible via the amount of personalized information about the physiological and biochemical makeup of individuals available in their electronic health record (EHR). This talk will outline a novel approach to combine EHR and dynamic PET imaging data in an optimization framework based on simulated annealing to non-invasively estimate the AIF. Techniques that will be outlined are applicable across imaging modalities, organs and diseases, such as functional imaging of prostate cancer images where increasingly more complex tracers are utilized for assessment and require AIF measurement.

Biography

Andrew F. Laine received his D.Sc. degree from Washington University (St. Louis) School of Engineering and Applied Science in Computer Science, in 1989 and BS degree from Cornell University (Ithaca, NY). He was a Professor in the Department of Computer and Information Sciences and Engineering at the University of Florida (Gainesville, FL) from 1990-1997. He joined the Department of Biomedical Engineering in 1997 and served as Vice Chair of the Department of Biomedical Engineering at Columbia University since 2003 - 2011. He is currently Chair of the Department of Biomedical Engineering and Director of the Heffner Biomedical Imaging at Columbia University and the Percy K. and Vida L. W. Hudson Professor of Biomedical Engineering and Professor of Radiology (Physics).

He has served on the program committee for the IEEE-EMBS Workshop on Wavelet Applications in Medicine in 1994, 1998, 1999, and 2004. He was the founding chair of the SPIE conference on “Mathematical Imaging: Wavelet Application in Signal and Image Processing”, and served as co-chair during the years 1993-2003. Dr. Laine has served as Chair of Technical Committee (TC-BIIP) on Biomedical Imaging and Image Processing for EMBS 2004-2009, and has been a member of the TC of IEEE Signal Processing Society, TC-BISP (Biomedical Imaging and Signal Processing) 2003-present. Professor Laine served on the IEEE ISBI (International Symposium on Biomedical Imaging) steering committee, 2006-2009 and 2009 – 2012. He was the Program Chair for the IEEE EMBS annual conference in 2006 held in New York City and served as Program Co-Chair for IEEE ISBI in 2008 (Paris, France). He served as Area Editor for IEEE Reviews in BME in Biomedical Imaging since 2007-2013. He was Program Chair for the EMBS annual conference for 2011 (Boston, MA). Professor Laine Chaired the Steering committee for IEEE ISBI, 2011-2013, and Chairs the Council of Societies for AIMBE (American Institute for Medical and Biological Engineers). Finally, he served as the IEEE EMBS Vice President of Publications 2008 – 2012, and currently the President of IEEE EMBS (Engineering in Biology and Medicine Society). He is a Fellow of IEEE and AIMBE.

Sensor Technologies for Multimodal Brain Interfacing

October 12 (Wednesday), 14:00-15:35, InterContinental Budapest, Ballroom I

Organized by the IEEE Sensors Council
Organizer: Walt Besio
Session Chairs: Michael H. Smith, Walt Besio

Toward Multimodal Massively Parallel Multichannel Brain-Sensing Interfaces

Mohamad Sawan, Polytechnique Montreal, Canada

Brain-Sensing Interfaces are emerging approaches and devices intended for understanding and subsequent treatment of complex neural vital functions which are provoked by Neurodegenerative Diseases. This talk covers Wearable Multimodal and implantable Biosensors-based systems intended for measurement and neurorecording respectively at action potential (AP) and neurotransmitter levels. Multichannel neurorecording of APs is achieved through compressive sampling and other compression techniques. However cell manipulation, detection, and characterization is based on either dielectrophoresis or magnetophoresis techniques followed by capacitive sensing and frequency monitoring. The wearable multimodel system offers measurement by up to 32 EEG and 256 fNIRS channels. However, for the implantable devices they are built around custom made Laboratory-on-Chip (LoC) platforms which include microelectronics and cell interfaces (microelectrode arrays and/or microfluidic structures). These circuits require power management, low-power circuit, high-data rate and reliable wireless energy and data communication. The microfluidic structures group microchannels and interfaces to bioelectronics and to in situ medium through inlets/outlets. Case studies include: 1) epilepsy on-set seizure detection, 2) monitoring pH levels in cell culture medium through arrays of complementary (P&N) ion-sensitive field effect transistors (ISFETs); 3) Biosensing through magnetic immunoassay-based microsystems for detecting protein toxins in environment. Planar microcoil arrays and system packaging technique are among the challenging issues.

Nanocomposite hydrogel-based chemo-optical transducers and amplifiers: Towards neurochemical sensing

Mike McShane, Texas A&M University, USA

Neurosensing has traditionally emphasized the measurement of biopotentials, with more recent developments in optical and fMRI imaging of blood volume/oxygenation changes as well as electrodes/arrays for electrochemical sensing of neurotransmitters. Optical devices, including fiber optic probes, are complementary tools that offer some overlapping and some complementary features. For example, some optical methods can employ enzymes and monitor reaction products or co-substrates like enzyme electrodes. “Reagentless” and “label-free” sensors are most appropriate for neural sensing; they are also more challenging to achieve because of the need for selective capture molecules or complex spectral analysis to obtain target specificity. This talk will discuss opportunities and limitations of optical devices in neurochemical sensing of energy substrates and neurotransmitters, including use of micro/nanoparticle-enabled systems, from functionalized fiber probes to implantable hydrogels that may be addressed by different interrogation strategies. Our current research emphasis is on developing miniature, injectable biosensor implants with microscale and nanoscale organization to enable observation of interstitial biochemistry. These materials provide specificity through use of various receptors and enhance sensitivity through optical amplification; specifically, the hydrogel-based biochemical sensors exhibit sensitive response by luminescence intensity and lifetime or Raman scattering. Further, they employ materials that can integrate naturally with tissue, such as porous gels and microparticle suspensions, enhancing prospects for accurate, rapid response and long-term monitoring. Research-grade and early commercial prototype instrumentation to interrogate the implants will also be discussed. To conclude, the major remaining challenges to long-term *in vivo* biochemical monitoring with these systems will be highlighted.

Microfabricated Sensors and Devices for Chronic Brain Recording and Stimulation

Vanessa Tolosa, Lawrence Livermore National Laboratory, USA

The market for neuromodulation devices for scientific discovery and clinical therapies is quickly growing. Increasingly, the demand is towards more complex technologies that can record and stimulate at high channel counts for months to years at a time. To meet these demands, the neural engineering community has adopted microfabrication techniques from the integrated circuits industry to develop chronic, implantable neural interfaces for brain recording and stimulation. At Lawrence Livermore National Lab (LLNL), we are developing advanced neural interface technologies that aim to provide closed-loop neuromodulation therapies in humans and chronic, large-scale brain recording in small and large animal platforms. We design and fabricate microelectrode arrays using flexible polymer substrates and long-lasting electrode materials. We perform extensive electrical and electrochemical testing of the arrays and electrodes to determine failure modes and lifetime. We are developing devices for several applications including a “smart” DBS system capable of closed-loop neuromodulation using 4 – 8x greater channel count than commercially available DBS devices. This allows clinicians to treat brain disorders using a larger treatment parameter space. We are also developing a system that can record single-units across thousands of channels across the whole brain. To date, we have shown high quality single-unit recordings in rat for greater than 9.5 months, with non-human primate studies underway. We are developing biocompatible, high channel count, chronic neural technologies designed to advance clinical therapies and scientific knowledge. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory, contract number DE-AC52-07NA27344. LLNL Team: V. Tolosa, A. Tooker, T. Delima, K. Lee, S. Chen, D. Soscia, A. Belle, A. Ivanovskaya, M. Crosetti, T. Datta, J. Pebbles, S. Sundaram, E. Wheeler, A. Sperry. Former Members: S. Pannu, K. Shah, S. Felix

Concentric Electrodes for Noninvasive Bidirectional Brain-Machine Interfaces

Walt Besio, University of Rhode Island, USA

Epilepsy affects more people than multiple sclerosis, cerebral palsy, muscular dystrophy and Parkinson's combined. Although there are anti-seizure drugs and surgical interventions around 30% of the people with epilepsy still have seizures. Paralysis affects approximately 1 in 50 US citizens. There are no known cures for paralysis. This talk will describe the use of unique concentric ring electrodes for noninvasive neural activity sensing and, the reverse, electrical stimulation. We have developed focal noninvasive bi-directional interfaces for automatic seizure control. We have been able to noninvasively stop acute seizures from penicillin, pilocarpine and pentylenetetrazol. Further, we have shown that electroencephalography (EEG) from tripolar concentric ring electrodes (TCREs), or tEEG, result in significantly better real-time computer cursor control. The addition of functional near infrared spectroscopy (fNIRS) with tEEG further enhances the ability to recognize imagined movements. This Research supported in part by NSF award 1539068 to WB. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Science Foundation.

Optical-based Technologies for Brain Imaging and Manipulation

Jun Ohta, Nara Institute of Science and Technology, Japan

Recently, combination of genetic engineering and optical technology makes it possible to bidirectional optical communication with brain. By introducing gene transfer technology, fluorescent protein such as GFP enables an optical tag, and photoactive protein such as ChR2 enables optical manipulation. Conventionally, a fluorescent microscope has been used for imaging and optical stimulation. It is, however, difficult to apply the method to a freely-moving mouse due to its requirement of fixing the mouse under a microscope stage. We have developed a miniaturized optoelectronic device which employs a dedicated CMOS image sensor and micro light emitting devices (LEDs), and can be implanted in the deep brain of a mouse to optically measure and control the brain functions of the mouse. The device is so light in its weight that a mouse implanted the device can move freely. In this presentation, I introduce some kinds of optoelectronic devices for measuring and controlling biological functions of freely-moving mice. Next, I describe our developed optoelectronic devices that can be implanted in a mouse deep brain. The fundamental device structure and performance are mentioned and some experimental results in vivo are demonstrated. Finally, future direction is addressed for achieving bidirectional optical communication with brain.

Joining SMCS BMI Technical Committee

You are welcome to join SMCS Technical Committee on Brain-Machine Interface Systems. You do not have to be a SMC Society member to join our TC, although we do encourage you to become one in order to benefit from a wide range of professional activities and privileges.

To join SMC's BMI TC, contact via e-mail a BMI TC Co-Chair and provide your name, title, position, affiliation, and a self-introduction.

We hope you will enhance your professional skills and potential through your activities in our Technical Committee.

Our Goal

Brain-Machine Interfaces (BMI) are about transforming thought into action, or, conversely, sensation into perception. One example of this paradigm contends that a user can perceive sensory information and enact voluntary motor actions through a direct interface between the brain and a prosthetic device in virtually the same way that we see, hear, walk, or grab an object with our own natural limbs.

The primary objective of the BMI Systems Technical Committee is to bring together specialists from the different areas that will be required as part of any real-world BMI system: systems neuroscience, system integration, sensors, integrated circuits, machine learning, control, robotics, biology, clinical studies, neurologists, system engineers, cybernetic experts, human-machine professionals, and other computer scientists and engineers working in this interdisciplinary environment. The goal of the TC is to provide a basis for the exchange of information and resources among these diverse communities, to enable interactions between groups from these fields and to bring a systems perspective to the field of BMI.

Join Us

- Interact with experts in Brain Machine Interface Systems, which is a relatively new and rapidly growing research field. Both invasive and non-invasive techniques (BCI) for interfacing the brain are included.
- Participate in interesting conferences and workshops.
- Make friends from different regions of the world.
- Exchange research ideas and possibly share research resources.

Additional Information:

http://www.ieeesmc.org/technical-activities/human-machine-systems/brain-machine-interface-systems

BMI Papers I – Performance Metrics and Human Factors for BMI Training and Operation (BMI Workshop Special Session VI)

Organizers: R. Chavarriaga, F. Lotte, C. Jeunet
October 11 (Tuesday), 09:30-11:00, InterContinental Budapest, Panorama I
Session Chairs: T. Zander, C. Jeunet

#1225 Supervision of time-frequency features selection in EEG signals by a human expert for brain–computer interfacing based on motor imagery

Alban Duprès (FR), François Cabestaing (FR), José Rouillard (FR)

In the context of brain–computer interfacing based on motor imagery, we propose a method which allows an expert to select manually time-frequency features. This selection is performed specifically for each subject, by analysing a set of curves that emphasize differences of brain activity recorded from electroencephalographic signals during the execution of various motor imagery tasks. We will show that expert knowledge is very valuable to supervise the selection of a sparse set of significant time-frequency features. Features selection is performed through a graphical user interface to allow an easy access to experts with no specific programming skills. In this paper, we compare our method with three fully-automatic features selection methods, using dataset 2A of BCI competition IV. Results are better for five of the nine subjects compared to the best competing method.

#1394 Mastery confidence influences P300 based Brain-Computer Interface (BCI) Performance

Sonja Kleih (DE)

In this study we investigated the effect of mastery confidence manipulation on BCI performance and P300 amplitude. We used a 6x6 P300 speller matrix and participants spelled words containing five letters each. Using a cover story, thirty-six participants were misinformed that they would use classification algorithms of diverse difficulty in three experimental blocks (easy, medium, hard condition). According to classification accuracy, a varying number of mistakes would occur. To support our cover story, we implemented a fake feedback which fed back one mistake in the easy condition, two mistakes in the medium condition and four mistakes in the hard condition per word. We found no significant effect of our mastery confidence manipulation. Neither P300 amplitude nor performance accuracy differed between conditions. We conclude that either we could not successfully manipulate mastery confidence or mastery confidence as a psychological variable cannot contribute to substantial explanation of variance in BCI performance.

#1918 A Task-Independent Workload Classifier for Neuroadaptive Technology: Preliminary Data

Laurens Ruben Krol (DE), Sarah Christin Freytag (DE), Markus Fleck (DE), Klaus Gramann (DE), Thorsten Oliver Zander (DE)

Passive brain-computer interfacing allows computer systems direct access to aspects of their user's cognition. In essence, a computer system can gain information about its user without this user needing to explicitly communicate it. Based on this information, human-computer interaction can be made more symmetrical, solving an age-old but still fundamental problem of present-day interaction techniques. For practical real-world application of this technology, it is important that cognitive states can be identified accurately and efficiently. Here we present preliminary data demonstrating it is possible to calibrate a task-independent classifier to identify when a user is under heavy workload across different activities. We used different types of mental arithmetic and even a semantic task. Task-independent classification is an important step towards real-world practical application of this technology.

#2083 Towards a Spatial Ability Training to Improve Motor Imagery based Brain-Computer Interface (MI-BCI) Performance: a Pilot Study

Suzy Teillet (FR), Fabien Lotte (FR), Bernard N'Kaoua (FR), Camille Jeunet (FR)

Although Mental Imagery based Brain-Computer Interfaces (MI-BCIs) seem to be very promising for many applications, they are still rarely used outside laboratories. This is partly due to suboptimal training protocols, which provide little help to users learning how to control the system. Indeed, they do not take into account recommendations from instructional design. However, it has been shown that MI-BCI performances are significantly correlated to certain aspects of the users' cognitive profile, such as their Spatial Abilities (SA). Thus, it remains to be elucidated whether training the SA of BCI users would also improve their BCI control performance. Therefore, we proposed and validated an SA training that aimed at being included in an MI-BCI training protocol. Our pre-studies indeed confirmed that such a training does increase people's SA abilities. We then conducted a pilot study with 3 participants, one with a standard MI-BCI training protocol, one with the proposed SA training integrated into a standard MI-BCI training, and another control integrating another training, here verbal comprehension tasks, into a standard MI-BCI training. While such a small population cannot lead to any strong result, our first results show that SA training can indeed be integrated into MI-BCI training and is thus worth being further investigated for BCI user training.

BMI Papers II – Adaptive and Self-Calibrating BMI Systems for Independent Use (BMI Workshop Special Session II)

Organizers: R. Chavarriaga, R. Scherer
October 11 (Tuesday), 09:30-11:00, InterContinental Budapest, Panorama V
Session Chairs: R. Chavarriaga, R. Scherer

#1123 Restricted Boltzmann Machines in Sensory Motor Rhythm Brain-Computer Interfacing: A Study on Inter-Subject Transfer and Co-Adaptation

Reinmar Josef Kobler (AT), Reinhold Scherer (AT)

Naive users often perceive calibration of a Sensory Motor Rhythm (SMR) based Brain-Computer Interfaces (BCI) as tedious and lengthy. The lack of feedback during training is assumed to be a major cause. I.e. if one had already a reasonable model to start with, feedback training could be started immediately. One concept to address this issue is learning a general model and adapting it to new observations. In this study we applied this concept by utilizing a generative model entitled Restricted Boltzmann Machine (RBM). We investigated its feature extraction capabilities by fitting a RBM to recordings of 9 subjects. Generalization was assessed in an online coadaptive study, covering 12 volunteers (10 naive). An overall median accuracy of 88.9% (83.5% naive) with a standard-error of 6.5% (6.6% naive) was achieved for a classical hand versus feet motor imagery task. The online co-adaptive training itself lasted approximately 25 minutes. Feedback was already presented after a one minute setup run, whose purpose was to estimate initial statistics and to train an online artifact detection system.

#1196 Spectral Meta-Leaner for Regression (SMLR) Model Aggregation: Towards Calibrationless BCI

Dongrui Wu (US), Vernon Lawhern (US), Stephen Gordon (US), Brent Lance (US), Chin-Teng Lin (TW)

To facilitate the transition of brain-computer interface (BCI) systems from laboratory settings to real-world application, it is very important to minimize or even completely eliminate the subject-specific calibration requirement. There has been active research on calibrationless BCI systems for classification applications, e.g., P300 speller. To our knowledge, there is no literature on calibrationless BCI systems for regression applications, e.g., estimating the continuous drowsiness level of a driver from EEG signals. This paper proposes a novel spectral meta-learner for regression (SMLR) approach, which optimally combines base regression models built from labeled data from auxiliary subjects to label offline EEG data from a new subject. Experiments on driver drowsiness estimation from EEG signals demonstrate that SMLR significantly outperforms three state-of-the-art regression model fusion approaches. Although we introduce SMLR as a regression model fusion in the BCI domain, we believe its applicability is far beyond that.

#1646 Multi-Task Logistic Regression in Brain-Computer Interfaces

Karl-Heinz Fiebig (DE), Vinay Jayaram (DE), Jan Peters (DE), Moritz Grosse-Wentrup (DE)

A brain-computer interface (BCI) is used to enable communication between humans and machines by decoding elicited brain activity patterns. However, these patterns have been found to vary across subjects or even for the same subject across sessions. Such problems render the performance of a BCI highly specific to subjects, requiring expensive and time-consuming individual calibration sessions to adapt BCI systems to new subjects. This work tackles the aforementioned problem in a Bayesian multi-task learning (MTL) framework to transfer common knowledge across subjects and sessions for the adaptation of a BCI to new subjects. In particular, a recent framework, that is able to exploit the structure of multi-channel electroencephalography (EEG), is extended by a Bayesian hierarchical logistic regression decoder for probabilistic binary classification. The derived model is able to explicitly learn spatial and spectral features, therefore making it further applicable for identification, analysis and evaluation of paradigm characteristics without relying on expert knowledge. An offline experiment with the new decoder shows a significant improvement in performance on calibration-free decoding compared to previous MTL approaches for rule adaptation and uninformed models while also outperforming them as soon as subject-specific data becomes available. We further demonstrate the ability of the model to identify relevant topographies along with signal band-power features that agree with neurophysiological properties of a common sensorimotor rhythm paradigm.

#2269 Unsupervised Adaptive Transfer Learning for Steady-State Visual Evoked Potential Brain-Computer Interfaces

Nicholas R Waytowich (US), Josef Faller (US), Javier O Garcia (US), Jean M Vettel (US), Paul Sajda (US)

Recent advances in signal processing for the detection of Steady-State Visual Evoked Potentials (SSVEPs) have moved away from traditionally calibrationless methods, such as canonical correlation analysis, and towards algorithms that require substantial training data. In general, this has improved detection rates, but SSVEP-based brain-computer interfaces (BCIs) now suffer from the requirement of costly calibration sessions. Here, we address this issue by applying transfer learning techniques to SSVEP detection. Our novel Adaptive-C3A method incorporates an unsupervised adaptation algorithm that requires no calibration data. Our approach learns SSVEP templates for the target user and provides robust class separation in feature space leading to increased classification accuracy. Our method achieves significant improvements in performance over a standard CCA method as well as a transfer variant of the state-of-the art Combined-CCA method for calibrationless SSVEP detection.

#2278 Closed-loop regulation of user state during a boundary avoidance task

Josef Faller (US), Sameer Saproo (US), Victor Shih (US), Paul Sajda (US)

Pilot induced oscillations (PIOs) are potentially catastrophic events that occur during flight when pilots attempt to control an aircraft close to a performance or physical boundary. PIO-like behavior is typically observed in boundary avoidance tasks (BAT), which simulate tight performance or physical boundaries and induce high cognitive workload. Our previous research linked the occurrence of PIO-like behavior to network level activity in the brain, where higher states of arousal reduce the flexibility of decision making networks such that less environmental information was incorporated to dynamically adjust action. This led us to hypothesize that down regulating arousal via closed-loop audio feedback of a user state could improve piloting performance by enabling increased decision flexibility. Here we show our initial results testing this hypothesis, where we use a hybrid brain computer interface (hBCI) to dynamically provide feedback to a pilot" that facilitates their ability to reduce their state of arousal. We conduct a systematic comparison relative to control and sham conditions and test to see if this feedback increases the time a "pilot" can fly before a catastrophic PIO. We find that hBCI feedback, which includes CNS components consistent with theta activity in the anterior cingulate (ACC), enables prolonged flight relative to closed-loop control and sham feedback. We also find that this feedback induces changes in pupil diameter which are absent in open-loop conditions and closed-loop conditions when feedback is not veridical. Pupil diameter has been reported as a surrogate measure of activity in the locus coeruleus-norepinephrine (LC-NE) system which is also linked to a circuit consisting of the ACC. We conclude that the feedback we induce with our hBCI provides preliminary evidence that self-regulation of LC-NE/ACC is possible and can be used to dynamically increase decision flexibility when under high cognitive workload.

BMI Papers III – Health and Non-Invasive Wearable BMI (BMI Workshop Special Session III)

Organizer: K. Khaderi
October 11 (Tuesday), 09:30-11:00, InterContinental Budapest, Ballroom I
Session Chairs: K. Khaderi, J. Libove

#2254 Cellular Wireless Energy Harvesting for EEG Applications on Smart Contact Lens

Luyao Chen (CA), Ehsan Kamrani (CA), Huayi Gao (CA)

An energy harvester for a smart contact lens that monitors epilepsy is developed here. The energy harvester is designed to rectify a portion of a cellular phone emitted uplink signal into DC power for the operations of on-lens EEG hardware. An electrically realistic human eye model is designed and fabricated using 3D printing technologies to assist in various measurements of the proposed energy harvester. A dipole antenna is fabricated and measured on the eye model to validate the power available for EEG to function.

#2280 The Visual System as a Proxy for Evaluation of Brain Function

Khizer R. Khaderi (US), Anna E. Nidecker (US), Peter Y Shen (US), Jeff H Pettey (US), Mohan K Reddy (US)

Purpose: Show how the visual system can be a proxy for brain function. Design: Original observational experiment Methods: Normal subjects underwent measurement of visual motility, pupillometry, and electroencephalogram for comparison with established and reported values Conclusion: The commercially available eye tracker and EEG band tested delivered values consistent with published normal control values. Further work with these devices on mild traumatic brain injury patients may provide important diagnostic and prognostic data for these injuries.

#2393 Auto-Powered Intraocular Lenses for Multi-Modal Brain Computer Interfacing

Ehsan Kamrani (CA)

A novel brain-machine interface (BCI) system for monitoring brain activities using functional intraocular lenses (IOL) has been introduced in this paper. It uses the correlation between the ocular signals with neural and hemodynamic activities to monitor and translate the brain dynamics to electric signal and then wirelessly delivers the data to the environment including external reader device or smartphone. A self-powered dual-modal BCI device embedded in an accommodative intraocular lens for electroencephalogram (EEG) and functional near infrared spectroscopy (fNIRS), is presented.

#2136 Wearable Brain Imager/BMI Technology for Structural, Vascular and Functional Extraction

Joel Libove (US), David Schriebman (US), Mike Ingle (US), Bernt Wahl (US)

Portable, low power, low-cost, flexible wearable Brain Machine Interfaces (BMIs) for real time brain imaging, with far higher potential spatial resolution than EEG, are being designed and prototyped using new chip architectures. Preliminary depth-indexed readings of real-time vascular and probable neural activity in the brain have been demonstrated using arrays of ultra-high dynamic range (160dB DANL) 1cm2 Ultra Wide Band (UWB) pulser/antenna/sampler assemblies. These ICs generate 5-300ps pulses and detect the resulting reflections from brain tissue boundaries. They cancel out 1/f noise, and are sensitive enough to detect energy reflected from deep tissues, as well as the signal transmitted through even the longest dimensions of the head, and display vascular pulsation and, for the first time, rudimentary indications of functional brain activity.

#2013 Real-Time Step Detection Using the Integrated Sensors of a Head-Mounted Display

Polona Caserman (DE), Patrick Hubert Krabbe (DE), Janis Wojtusch (DE), Oskar von Stryk (DE)

Recent improvements in virtual reality technology and head-mounted displays have led to a number of novel and innovative applications in entertainment, education, science and healthcare. The primary goal in most of these applications is to give the user a sensation of being part of the virtual reality. This focus on presence or immersion requires to create a connection between the user and the virtual environment but also between the user and his virtual avatar. Synchronizing the body movement of the user and his avatar can help to improve the feeling of presence by enhancing the experience of agency and body ownership over the avatar. A typical example is the combination of a head-mounted display and a treadmill to create a realistic walking or running simulation in a virtual environment. In this scenario, the synchronization of leg movement improves the feeling of presence and allows to further enhance the virtual experience, for example by adjusting gait parameters of the avatar or triggering customized stepping sounds. This paper presents a robust real-time step detector that uses the integrated sensors of a state-of-the-art head-mounted display and allows to recognize the pattern of individual steps. No additional sensors on the trunk or lower body are required. By applying a coordinate transformation and straightforward signal processing, it is possible to discriminate between left and right steps and detect the current walking speed. This information is used to animate a virtual avatar by scaling a predefined walking trajectory and to control the walking speed within a virtual environment.

BMI Papers IV – Real World Applications of Brain Computer Interface Systems (I) (BMI Workshop Special Session IV)

Organizer: V. A. Prasad
October 12 (Wednesday), 09:30-11:00, InterContinental Budapest, Panorama I
Session Chairs: V. A. Prasad, T. Mullen

#1007 Brain-machine Interfacing-based Teleoperation Control of A Wheeled Mobile Robot

Suna Zhao (CN), Zhijun Li (CN)

This paper describes the development of teleoperation control framework of a mobile robot through brain-machine interface. Utilizing the remote images of environment, transferred to the human operator, visual compressive feedback loop produces imagine errors in non-vector space, where images are considered as a set without image processing of feature extraction. Given an initial set and a goal set, EEG motion commands are evoked to make the error of the two sets converge to zero. The online BMI (Brain Machine Interface), utilizing steady state visually evoked potentials (SSVEP), analyzes the human EEG data in such a format that human intentions can be recognized by AdaBoostSVM classifier and motion commands produced for the teleoperated robot. Bezier curve is utilized to parameterize the motion commands and the low level motion controller to track the reference trajectory. Extensive experimental studies have been done to assess the performance of the proposed BMI system.

#1448 Voice Familiarity Detection using EEG-based Brain-Computer Interface

Mahesh Kallelil (IN), Smitha Kavallur (SG), Vinod Achutavarrier Prasad (SG)

Brain-Computer Interface (BCI) is a direct communication pathway between brain and external devices bypassing the natural pathway of nerves and muscles. BCI enables an individual to send commands to a peripheral device using his brain activity. Electroencephalogram (EEG) is the most commonly used brain signal acquisition method as it is simple, economical and portable. Feasibility of detecting familiar vs non-familiar voice signals using EEG signals has been investigated in this paper. The results show that combination of features such as mobility and complexity of the signal gives an average accuracy of 72.2% in classifying between familiar and unfamiliar voices among 8 subjects.

#1811 A Novel Supervised Locality Sensitive Factor Analysis to Classify Voluntary Hand Movement in Multi-Direction Using EEG Source Space

Vikram Shenoy Handiru (SG), Vinod Achutavarrier Prasad (SG), Cuntai Guan (SG)

Recent advances in EEG-based brain–computer interfaces (BCIs) have shown that brain signals can be used to decode arm movement intention and execution in multiple directions. Conventional approaches use sensor space EEG for classifying movement related tasks. Sensorspace EEG can reveal only limited information about the trivial but complex tasks that involve higher degrees of freedom of the movement. On the contrary, source space analysis is expected to provide more information about the neurophysiological mechanism relevant to the task. To this end, we propose a novel source-space feature extraction technique based on supervised locality sensitive Factor analysis which approximates the neurophysiological functioning of our experimental data in a better way than that of a solely data-driven approach. EEG recordings in the sensor space are transformed into source space using the Weighted Minimum Norm Estimate (wMNE) method. We show that for a multi-class classification problem of classifying the EEG of voluntary arm movement in 4 orthogonal directions, the source space features offer a significant improvement in the classification accuracy compared to sensor space features. One-versus-rest (OVR) approach is used for multiclass classification with Fisher's Linear Discriminant (FLD) as the primary classifier.

#1839 Brain-Computer Interfacing for Multimedia Quality Assessment

Sebastian Bosse (DE), Klaus-Robert Müller (DE), Thomas Wiegand (DE), Wojciech Samek (DE)

Multimedia quality assessment is a central research field in information and media technology. Recently, brain- computer interfacing (BCI) based methods have been proposed to assess perceived quality. In this paper we give an overview on the state-of-the art and discuss open questions and challenges relevant to the BCI community.

#1947 EEG based Stress Level Identification

Guo Jun (SG), Smitha Kavallur (SG)

This paper investigates detection of patterns in brain waves while induced with mental stress. Electroencephalogram (EEG) is the most commonly used brain signal acquisition method as it is simple, economical and portable. An automatic EEG based stress recognition system is designed and implemented in this study with two effective stressors to induce different levels of mental stress. The Stroop colour-word test and mental arithmetic test are used as stressors to induce low level and high level of stress respectively, and their relevant C# applications are developed in Microsoft Visual Studio to interface with Emotiv Epoc device. Power band features from EEG signals are analyzed and using the relative difference of beta and alpha power as feature along with Support Vector Machine as classifier, three-levels of stress can be recognized with an accuracy of 75%. For two-level stress analysis, accuracy of 88% and 96% are achieved for Stroop colour-word test and mental arithmetic test respectively.

BMI Papers V – BMI for Motor/Cognitive Rehabilitation and Assistance (I) (BMI Workshop Special Session V)

Organizer: R. Chavarriaga
October 12 (Wednesday), 09:30-11:00, InterContinental Budapest, Panorama V
Session Chairs: G. Prasad, J. M. Azorin

#1070 Evaluating decoding performance of upper limb imagined trajectories during center-out reaching tasks

Andres Ubeda (ES), Jose M Azorin (ES), Ricardo Chavarriaga (CH), José del R. Millán (CH)

In recent years, several studies have shown that there is a correlation between electroencephalographic (EEG) signals and hand-reaching kinematic parameters after applying linear decoders. These studies have been generally conducted using actual upper limb movements, but so far there has been little discussion about the possibility of applying these decoders to motor imagery tasks. Moreover, the use of these decoders is rather controversial and there is no general agreement about the metrics used to compare decoded and real kinematics. In this paper, we have applied this methodology to upper limb imagined movements using a center-out protocol. Our results show that, although decoding performance is poor, there are significant components, particularly in horizontal imagined movements, that could be translated into reliable output commands. For this purpose, we have proposed a discrete classification of reached targets showing significant classification rates when the number of classified targets decreases.

#1198 The adjustment of muscle synergy recruitment by controlling muscle co-contraction during the reaching movement

Hiep Vu Nguyen Sy (JP), Isao Nambu (JP), Yasuhiro Wada (JP)

Muscle synergy is defined as a combination of the limited number of muscle activities, which has been considered useful for controlling a large number of degrees of freedom in the musculoskeletal system. In previous studies, the robustness of muscle synergy recruitment across biomechanical tasks has been reported, i.e., the central nervous system controls a few pre- organized muscle synergies corresponding to a specific motor behavior. In contrast, the present study considers a different hypothesis wherein muscle synergy recruitment can be affected by muscle contraction. In our experiment, the subjects were instructed to perform an additional muscle contraction during the eight directional point-to-point reaching movement, on the basis of visual feedback of four levels of contraction. The result of extracted muscle synergies from electromyogram across contraction levels that as the level of contraction increases, so does the number of recruited muscle synergy. Moreover, we found a high similarity between shared muscle synergies–the first synergy under different levels of contraction. The result revealed the hypothesis that pre-organized synergies may be responding to the specific motor task but this coordination of existing muscle synergies can be adjusted by muscle contraction. This adjustment can be useful to develop the more complex myoelectric interfaces efficiently which could control not only arm motion but also arm force.

#1444 Analyzing electrode configurations to detect intention of pedaling initiation through EEG signals

Marisol Rodriguez-Ugarte (ES), Alvaro Costa (ES), Eduardo Iañez (ES), Jose M Azorin (ES)

Restoring the gait cycle is vital in motor-impaired people. To accomplish this, it is necessary to study the brain signals in different areas. This work analyzes EEG data offline and pseudo-online for different electrode configurations and different processing-time windows to detect the pedaling start initiation. Premotor cortex is the area related to movement intention. Therefore, in this study, the FZ electrode, which is located in this area, was included in the analysis of the electrode configurations, testing whether it plays an important role in the detection of pedaling start intention. Results show that using time before and after the movement onset for processing is preferred. The presence of the FZ electrode seems to be desirable when analyzing data offline, but is not statistically significant when analyzing data pseudo-online. This suggests the FZ electrode could be ignored when analyzing data in real time, since the processing is the same as pseudo-online.

#1589 EMOHEX: An Eye Tracker based Mobility and Hand Exoskeleton Device for Assisting Disabled People

Yogesh Kumar Meena (GB), Anirban Chowdhury (IN), Hubert Cecotti (GB), KongFatt Wong-Lin (GB), Shyam Sunder Nishad (IN), Ashish Dutta (IN), Girijesh Prasad (GB)

People suffering from a variety of upper and lower limb disabilities due to different neuro-muscular diseases or injuries, often find it difficult to perform day-to-day activities of mobility and grasping (pick and place) objects. This paper presents the feasibility and utility of a newly developed assistive device named EMOHEX, for disabled people to perform some activities of daily living (ADL). EMOHEX is an integrated platform that combines a low cost eye-tracking device with a powered-wheelchair mounted hand-exoskeleton, which can assist disabled people in grasping objects while moving around. A dual control panel based graphical user interface is designed wherein the user's intention to select any command button is detected through eye-tracking. The dual control consists of wheelchair control panel and exoskeleton control panel, which are interchangeable by a switch button common to both the panels. The hand-exoskeleton is capable of assisting grasp, hold, and release action. Experiments conducted on 16 healthy subjects revealed that performance metrics were significantly ($p<0.01$) similar for the same task complexity while for different task complexities the performance metrics were significantly ($p<0.01$) different across all the subjects. These results showed the feasibility and stability of the system, respectively. Moreover, the information transfer rate (ITR) of eye-tracker was found satisfactory at 55.281.29 bits/min and 51.021.72 bits/min for simple and complex task, respectively. Thus, EMOHEX has the potential as a quality assistive device for disabled people.

BMI Papers VI – Neuroscience Based Design: Fundamentals and Applications (BMI Workshop Special Session I)

Organizers: R. Scherer, O. Sourina, S. C. Wriessneger
October 12 (Wednesday), 09:30-11:00, InterContinental Budapest, Duna Salon II
Session Chairs: R. Scherer, O. Sourina, S. C. Wriessneger

#1256 Evaluation of a Neurofeedback-based Cognitive Telerehabilitation System for Neurological Patients

Silvia Erika Kober (AT), Daniela Pinter (AT), Siegrid Fuchs (AT), Christa Neuper (AT), Christian Enzinger (AT), Guilherme Wood (AT)

Aim of this study was to provide a proof-of-principle for a neurofeedback-based cognitive telerehabilitation system. Here we describe the implementation of the system and its application and evaluation in two neurological patients with multiple sclerosis suffering from cognitive deficits. The portable telerehabilitation system consists of a small EEG amplifier, an easy-to-use semi-dry EEG headset and a laptop enabling home-based neurofeedback training. The patients performed ten home-based neurofeedback training sessions, which were supervised remotely by an EEG expert. During neurofeedback training, participants tried to voluntarily increase the amplitude of the sensorimotor rhythm (SMR, 12–15 Hz) in the EEG. Before and after neurofeedback training, cognitive functions were assessed using standardized neuropsychological tests. Results demonstrate the feasibility and efficacy of the neurofeedback-based cognitive telerehabilitation system on different levels. On the technical level, we could show that the system works flawlessly and can be easily used by neurological patients on their own at the patients' home. On the behavioral level, our results indicate that the effects of the home-based neurofeedback training are comparable to effects of conventional neurofeedback training performed in a standard lab or clinical environment. The patients were able to voluntarily modulate their own brain activity in the desired direction and they showed cognitive improvements after neurofeedback training compared to a pre-measurement. Hence, our study demonstrates the great potential value of such a neurofeedback-based telerehabilitation system for future cognitive rehabilitation.

#1499 Brain-Computer Interface adaptation for an end user to compete in the Cybathlon

Andreas Schwarz (AT), David Steyrl (AT), Gernot R Müller-Putz (AT)

Non-invasive brain-computer interfaces (BCI) aim to assist severely motor impaired persons in their daily life routine, however only a few BCIs have made it out of the laboratory. To foster further development, the Cybathlon, an international multi-discipline tournament, has been founded. One of the disciplines is the BCI-Race, where end users control avatars in a virtual race game by their thoughts. The game supports 4 different commands which accelerate the avatar and increase the chance to win. So far, no gold standard procedure has been established on how to enable, train and individualize multiclass BCI control for users. In this work we present a 4-stage procedure to closely tailor a multi-class BCI to an end user who will participate in the Cybathlon. In stage I we test for basic BCI-capability, in stage II we evaluate the most suitable mental tasks for the user and in stage III we test user compliance while perceiving feedback. Finally in stage IV the user is playing the competition game. Our procedure provides a promising way to guide users from first contact with BCI technology to actually play a videogame by thoughts. We demonstrate the feasibility of our procedure at the pilot of the GRAZ-BCI racing team MIRAGE91.We believe that an evidence based procedure, maybe similar to the one presented in this work is a necessity to introduce BCI technology in the daily life of potential end users.

#1722 Using Support Vector Regression to Estimate Valence Level from EEG

Zirui Lan (SG), Gernot R Müller-Putz (AT), Lipo Wang (SG), Yisi Liu (SG), Olga Sourina (SG), Reinhold Scherer (AT)

Emotion recognition is an integral part of affective computing. An affective brain-computer-interface (BCI) can benefit the user in a number of applications. In most existing studies, EEG (electroencephalograph)-based emotion recognition is explored in a classificatory manner. In this manner, human emotions are discretized by a set of emotion labels. However, human emotions are more of a continuous phenomenon than discrete. A regressive approach is more suited for continuous emotion recognition. Few studies have looked into a regressive approach. In this study, we investigate a portfolio of EEG features including fractal dimension, statistics and band power. Support vector regression (SVR) is employed in this study to estimate subject's valence level by means of different features under two evaluation schemes. In the first scheme, a SVR is constructed with full training resources, whereas in the second scheme, a SVR only receives minimal training resources. MAE (mean absolute error) averages of 0.74 and 1.45 can be achieved under the first and the second scheme, respectively, by fractal feature. The advantages of a regressive approach over classificatory approach lie in continuous emotion recognition and the possibility to reduce training resources to minimal level.

#1894 Assessing Haptic Video Interaction with Neurocognitive Tools

Shahzad Rasool (SG), Xiyuan Hou (SG), Yisi Liu (SG), Alexei Sourin (SG), Olga Sourina (SG)

Haptic interaction is a form of a user-computer interaction where physical forces are delivered to the user via vibrations, displacements and rotations of special haptic devices. When quality of the experience of the haptic interaction is assessed, mostly subjective tests using various questionnaires are performed. We proposed novel neurocognitive tools for assessing both overall experience of the haptic interaction, as well as particular time-stamped activities. Our assessment tools are based on recognition of emotions and stress obtained from Electroencephalograms (EEG). We used them in a feasibility study on adding haptic interaction to Skype video conversation.

#2112 Lets play Tic-Tac-Toe: A Brain-Computer Interface case study in cerebral palsy

Reinhold Scherer (AT), Andreas Schwarz (AT), Gernot R Müller-Putz (AT), Viktoria Pammer-Schindler (AT), Mariano Lloria Garcia (ES)

Operating Brain-Computer Interfaces (BCIs) that are based on the detection of changes in oscillatory non- invasive electroencephalogram (EEG) typically involves learning. Commonly, the learning process is distributed between the user (reliable EEG pattern generation) and the machine (robust EEG pattern detection). Standard training approaches, however, typically do not allow users to gain meaningful levels control. A better understanding of brain functioning or the use of sophisticated machine learning are ways to enhance control. Rethinking training paradigms is another option. In this paper, we enhance our game-based training approach by adding competitive elements. Winning is a powerful motivator that increases user engagement of the typically boring BCI training experience. We report on an end user with cerebral palsy who successfully gained BCI control and played the classical Tic-Tac-Toe game against his caregiver.

BMI Papers VII – BMI for Neurodriving (BMI Workshop Special Session VII)

Organizers: S-W. Lee, J.d.R. Millán
October 12 (Wednesday), 09:30-11:00, InterContinental Budapest, Ballroom I
Session Chairs: S-W. Lee, J.d.R. Millán

#1221 Dynamic Potential-Model-Based Feature for Lane Change Prediction

Hanwool Woo (JP)

We propose a prediction method for lane changes of other traffic participants. According to previous research, over 90% of car crashes are caused by human mistakes, and lane changes are the main factor. Therefore, if an intelligent system can predict a lane change and alarm a driver before another vehicle crosses the center line, this can contribute to reducing the accident rate. The main contribution of this work is to propose a new feature describing the relationship of a vehicle to adjacent vehicles. We represent the new feature using a dynamic characteristic potential field that changes the distribution depending on the relative number of adjacent vehicles. The new feature addresses numerous situations in which lane changes are made. Adding the new feature can be expected to improve prediction performance. We trained the prediction model and evaluated the performance using a real traffic dataset with over 900 lane changes, and we confirmed that the proposed method outperforms previous methods in terms of both accuracy and prediction time.

#1417 Classification of Movement-related Cortical Potentials for Multi-Command Control based on Brain-Machine Interface

Ji Yong Kim (KR), Seong-Whan Lee (KR)

Decoding of various motor intentions for generating command is one of the important factors in brain-based wheelchair system. The goal of this study focuses on classifying four types of trunk-related motor execution and imagery intentions. By brain components which are related to the trunk-related movements (waist, shoulder, and trunk) are generated in the very small and very close brain areas; therefore, decoding of trunk-related motor intentions are not easy for providing reliable system commands. To the best of our knowledge, the problems mentioned above have not been explored in the literature. In this study, we first validated the decoding accuracy of trunk-related motor intention based movement-related cortical potential. A set of binary classification performance which are shoulder extension (SE), waist rotation (WR), trunk flexion (TF), and rest (RE) have validated in respect to execution movement as well as imagery movement across six subjects. All binary classification results showed performance that is higher than the chance level. The best decoding accuracy shows 68.5% in the motor imagery task of shoulder extension vs. waist rotation.

#1496 A Hand Gesture based Driver-Vehicle Interface to Control Lateral and Longitudinal Motions of an Autonomous Vehicle

Udara Eshan Manawadu (JP), Mitsuhiro Kamezaki (JP), Masaaki Ishikawa (JP), Takahiro Kawano (JP), Shigeki Sugano (JP)

Autonomous vehicles would make the future roads safer by keeping the human driver out of the loop. However, reduced degree of human-control could result in loss of the feeling of driving for some drivers. Therefore, in this study we proposed a method of interaction between the driver and autonomous vehicle by allowing the driver to control the vehicle's lateral and longitudinal motions. We adopted hand gestures as input modality because it can reduce driver's visual and cognitive demands. We first derived seven fundamental vehicle maneuvers to improve driver experience, and related them to seven independent hand gestures. We then created a hand gesture interface to control an autonomous vehicle, using Leap Motion as the gesture recognition platform. We conducted driving experiments involving twenty drivers in a virtual reality driving simulator to investigate the effectiveness of this interface for vehicle control. We evaluated the driving experience and drivers' opinions regarding the gestural interface. The results proved that semi-autonomous controlling using the hand gesture interface significantly reduced drivers' perceived workload.

#1667 Towards an EEG-based Intelligent Wheelchair Driving System with Vibro-tactile Stimuli

Keun-Tae Kim (KR), Seong-Whan Lee (KR)

Nowadays, the electroencephalography (EEG)-based wheelchair driving system, one of the major applications of brain-computer interface (BCI), that allows an individual with mobility impairments to perform daily living activities independently. In this context, user's intention identifying methods were developed by several research groups using various paradigms for the wheelchair driving. In this study, we use a steady-state somatosensory evoked potential (SSSEP) paradigm, which elicits brain responses to vibro-tactile stimulation of specific frequencies, for a user's intention identification to driving a wheelchair. The main focus of this study is to validate an effectiveness of our SSSEP-based wheelchair driving system via an online experiment with more challenging tasks than our recent study. In our system, a subject concentrated on one of vibro-tactile stimuli (attached on left-hand, right-hand, and foot) selectively for driving wheelchair (corresponding to turn-left, turn-right, and move-forward). Five healthy subjects participated in the online experiment, and the experimental results show that our SSSEP paradigm is suitable to EEG-based intelligent wheelchair driving system.

BMI Papers VIII – Machine Learning Methods for Brain-Computer Interfacing (I) (BMI Workshop Special Session VIII)

Organizer: R. Chavarriaga
October 12 (Wednesday), 09:30-11:00, Sofitel Budapest Chain Bridge, Bellevue 2
Session Chairs: R. Chavarriaga, M. Clerc

#1179 Spatial filters yield stable features for error-related potentials across conditions

Iwane Fumiaki (JP), Ricardo Chavarriaga (CH), Inaki Iturrate (CH), José del R. Millán (CH)

Error-related potentials (ErrP) have been increasingly studied in psychophysical experiments as well as for brain- machine interfacing. In the latter case, the generalisation capabilities of ErrP decoders is a crucial element to avoid frequent recalibration processes, thus increasing their usability. Previous studies have suggested that ErrP signals are rather stable across recording sessions. Also, studies using protocols of serial stimuli presentation show that these potentials do not change significantly when the presentation rate. Here we complement these studies by analysing the decoding generalisation capabilities. Using data from monitoring experiments, we evaluate how much the performance degrades when tested in a condition different than the one the decoder was trained with. Moreover, we compare different spatial filtering techniques to see which preprocessing steps yield less-sensitive features for ErrP decoding.

#1192 Agreement Rate Initialized Maximum Likelihood Estimator for Ensemble Classifier Aggregation and Its Application in Brain-Computer Interface

Dongrui Wu (US), Vernon Lawhern (US), Stephen Gordon (US), Brent Lance (US), Chin-Teng Lin (TW)

Ensemble learning is a powerful approach to construct a strong learner from multiple base learners. The most popular way to aggregate an ensemble of classifiers is majority voting, which assigns a sample to the class that most base classifiers vote for. However, improved performance can be obtained by assigning weights to the base classifiers according to their accuracy. This paper proposes an agreement rate initialized maximum likelihood estimator (ARIMLE) to optimally fuse the base classifiers. ARIMLE first uses a simplified agreement rate method to estimate the classification accuracy of each base classifier from the unlabeled samples, then employs the accuracies to initialize a maximum likelihood estimator (MLE), and finally uses the expectation-maximization algorithm to refine the MLE. Extensive experiments on visually evoked potential classification in a brain-computer interface application show that ARIMLE outperforms majority voting, and also achieves better or comparable performance with several other state-of-the-art classifier combination approaches.

#1193 Offline EEG-Based Driver Drowsiness Estimation Using Enhanced Batch-Mode Active Learning (EBMAL) for Regression

Dongrui Wu (US), Vernon Lawhern (US), Stephen Gordon (US), Brent Lance (US), Chin-Teng Lin (TW)

There are many important regression problems in real-world brain-computer interface (BCI) applications, e.g., driver drowsiness estimation from EEG signals. This paper considers offline analysis: given a pool of unlabeled EEG epochs recorded during driving, how do we optimally select a small number of them to label so that an accurate regression model can be built from them to label the rest? Active learning is a promising solution to this problem, but interestingly, to our best knowledge, it has not been used for regression problems in BCI so far. This paper proposes a novel enhanced batch-mode active learning (EBMAL) approach for regression, which improves upon a baseline active learning algorithm by increasing the reliability, representativeness and diversity of the selected samples to achieve better regression performance. We validate its effectiveness using driver drowsiness estimation from EEG signals. However, EBMAL is a general approach that can also be applied to many other offline regression problems beyond BCI.

#1359 Classification of 17 Voluntary Movements Using Principal Component Analysis for Myoelectric Prosthetic Hand

Emi Nakanishi (JP), Trongmun Jiralerspong (JP), Asuka Kambayashi (JP), Jun Ishikawa (JP)

This paper proposes a signal processing technique to classify 17 voluntary movements from electromyographic (EMG) signals. In the proposed method, EMG signals are acquired from six EMG sensors. The features of the voluntary movements are extracted from these EMG signals using principal component analysis and later classified using artificial neural network (ANN). To evaluate the validity of the proposed method, online classification experiments are conducted on one male and one female participants. A total of 15 data sets, where each set consists of EMG signals characterizing the 17 motions, are acquired from each participant. From this total, five data sets are used as training data, while the other 10 data sets are acquired for online testing. The same experiments are repeated on a different day. The validity of the algorithm, evaluated based on the mean correct and incorrect classification rates of both days are calculated from testing data. Results show that using all five training data to train the ANN yields higher accuracy than using only one training data. The best classification result shows that there are 10 out of 17 motions with an accuracy of over 50% and mean incorrect rate of 2%. Furthermore, classification where ANN is trained using training data of a different day is also conducted. The results show that the proposed algorithm can achieve an overall correct rate of 46% at best. Based on the above results and considering the fact that users can promptly modify any erroneous actions by looking at the actual output of the prosthesis, the proposed algorithm has demonstrated the potential to classify 17 voluntary movements from 6 EMG sensors.

#1590 Novel Parameter Tuned Methodology for Under-damped Stochastic Resonance Applied to EEG Signal Enhancement

Lucio Fidel Rebolledo-Herrera (MX), Guillermo Espinosa F.V. (MX)

In this article, motor imagery ElectroEncephalographic (EEG) signals for Brain-Computer interfaces (BCI) are processed under a weak signal detection (WSD) paradigm, due to low signal to noise ratio (SNR) presented in EEG. Based on results from our previous work, Stochastic resonance (SR) is first time proposed as a WSD method for EEG signals thus, taking advantage of the noise transitions on a double well system. These transitions are synchronized with the brain rhythms embedded in the EEG signal, enhancing desired brain waves. This way, a novel parameter tuned SR was applied, based on bi-stable well separation and depth modulation on the Duffing system, recovering most of the input waveform shape. On the other hand, a recognized international EEG dataset, generated under BCI paradigms, was used in this work. The estimated SNR was 24dB and, after SR processing, signal recovery on the desired mu-beta band was observed, with an output SNR of 1.31dB during motor imagery and 1.41dB during resting states. Single EEG signal is reported from 17 channels processed, in order to demonstrate the signal processing methodology. Also for comparative purposes, dyadic wavelet transform (DWT) was also applied to the same EEG signal. The results have shown comparable or, even a better signal enhancement than DWT.

BMI Papers IX – Neurostimulation and BMI (BMI Workshop Special Session IX)

Organizer: C.S. Nam
October 12 (Wednesday), 09:30-11:00, Sofitel Budapest Chain Bridge, Bellevue 3
Session Chairs: C.S. Nam, M.C. Thompson

#1339 Comparison of Reaction Times in Response to Electrical and Visual Stimulation Using a High-speed Camera

Sho Tatsuno (JP), Tomohiko Hayakawa (JP), Masatoshi Ishikawa (JP)

Recently, information about reaction times in response to perceptive stimulation has been used to develop several applications focused on movement instruction. However, knowledge is still lacking about reaction time related to haptics, especially electrical stimulation. Therefore, in this study we measured and analyzed reaction time in response to electrical and visual stimulation in human participants using a 250 fps high-speed camera. In our experimental process, participants were placed in a separate room and they wore soundproof headphones to shield them from external noise. Subsequently, they conducted reaching tasks involving visual and electrical stimuli. Using a high-speed camera, we recorded participants' hand motions from a top view (thereby focusing on the backs of their hands) and calculated their reaction time via image processing. The results show that reaction time in response to electrical stimulation is approximately 200 ms, which is more than 35% faster than reaction time in response to visual stimulation. Consequently, our results could augment basic knowledge about electrical stimulation in real-time feedback systems. The data obtained may help in electrical application in high-speed use.

#1650 A Hybrid BCI-Controlled FES System for Hand-Wrist Motor Function

Inchul Choi (US), Kyle Bond (US), Chang Soo Nam (US)

Motor imagery (MI) based Brain-Computer Interfaces (BCIs) controlled Functional Electrical Stimulation (FES) can help people with severe neuromuscular impairments to control their limbs by bypassing peripheral nerves and muscle pathways. However, there are still four major limitations with current MI-based BCIs for FES control: 1) They require relatively longer training and the training procedures are not clear. 2) Classification of different MI tasks within the same limb is difficult 3) MI features cannot be utilized during passive hand-motions induced by FES due to movement artifacts. 4) Few FES units are available which have real-time parameter control functionality. This study addresses these limitations by applying a hybrid BCI paradigm with a modified low-cost commercial off-the-shelf Transcutaneous Electrical Nerve Stimulation (TENS) unit. Four subjects were asked to mimic visual cues to imagine either closing or opening their dominant hand at different rates, such as fast or slow. After FES was initiated, the subjects were asked to attend to visual stimulus to elicit Steady-State Visual Evoked Potential (SSVEP) to stop FES. Results of this study showed that the modified TENS unit was able to successfully control hand motion in real-time. The classification results of different MI tasks within the same hand were promising. Furthermore, all subjects could stop the FES within 6 seconds and the average completion time was 2 seconds. The results of this study could provide insights towards future research of rehabilitation for stroke patients.

#1840 A Study on the Effect of Electrical Stimulation During Motor Imagery Learning in Brain-Computer Interfacing

Saugat Bhattacharyya (FR), Maureen Clerc (FR), Mitsuhiro Hayashibe (FR)

Functional Electrical Stimulation (FES) stimulates the affected region of the human body thus providing a neuroprosthetic interface to non-recovered muscle groups. FES in combination with Brain-computer interfacing (BCI) has a wide scope in rehabilitation because this system can directly link the cerebral motor intention of the users with its corresponding peripheral mucle activations. Such a rehabilitative system would contribute to improve the cortical and peripheral learning and thus, improve the recovery time of the patients. In this paper, we examine the effect of electrical stimulation by FES on the electroencephalography (EEG) during learning of a motor imagery task. The subjects are asked to perform four motor imagery tasks over six sessions and the features from the EEG are extracted using common spatial algorithm and decoded using linear discriminant analysis classifier. Feedback is provided in form of a visual medium and electrical stimulation representing the distance of the features from the hyperplane. Results suggest a significant improvement in the classification accuracy when the subject was induced with electrical stimulation along with visual feedback as compared to the standard visual one.

#1866 Demonstration of a stable chronic electrocorticography-based brain-computer interface using a deep brain stimulator

Margaret Claire Thompson (US), Jeffrey Herron (US), Timothy Brown (US), Jeffrey Ojemann (US), Andrew Ko (US), Howard J Chizeck (US)

Chronic electrocorticography (ECoG) studies will be necessary to understand how end-users of assistive brain-computer interface (BCI) technologies will control their devices on a long-term scale. A BCI platform consisting of a deep brain stimulator (DBS) and a cortical electrode strip, theoretically suitable for use over multi-year periods, is validated in a single human subject with essential tremor (ET). At the time of this writing, stable ECoG recordings have been demonstrated for four months after implantation. Additionally, the patient has performed a BCI cursor-control task with better-than-chance accuracy using both (1) an overt movement control scheme and (2) a motor imagery control scheme. These results validate the sensing-enabled DBS with cortical strip system as an exciting platform for chronic ECoG BCI experiments and as a scientific tool for long-term cortical recordings in different patient populations.

#1938 Multichannel Cuff Electrodes for Peripheral Nerve Stimulation and Recording

Emma Brunton (GB), Christoph Blau (GB), Kianoush Nazarpour (GB)

In the development of neuroprostheses to restore sensory and motor function to disabled patients the choice of the electrodes to be used remains an important consideration. The optimal electrode design should be minimally invasive and be capable of recording or stimulating selectively a large number of nerve fibers. Additionally, the electrodes should be capable of delivering stimulation within electrochemically safe limits. Here we report on the use of a multi-contact cuff electrode for stimulation and recording from peripheral nerves. Nerve cuffs with 16 electrodes, comprising 4 rings of 4 electrodes, were implanted around the sciatic nerve of two rats. The electromyogram signal (EMG) was recorded in response to electrical stimulation delivered by the electrodes, and the electroneurogram signal (ENG) was recorded in response to sensory stimulation applied to the ipsilateral foot. Visually detectable muscle movements were elicited with charge injections ranging from 4.6 to 8.2 nC. ENG recordings in response to sensory stimulus allowed for the onset and culmination of sensory stimulation to be detected using mean absolute value of the signal. Initial results indicate that flexion and extension of the ankle joint can be differentiated by combining information recorded from pairs of electrodes. The results of this study indicate that multi-contact cuffs can be used for decoding neural signals; however, more data needs to be collected for classification of sensory movements to be tested.

BMI Papers X – Real World Applications of Brain Computer Interface Systems (II) (BMI Workshop Special Session X)

Organizer: V. A. Prasad
October 12 (Wednesday), 11:00-12:30, InterContinental Budapest, Panorama I
Session Chairs: V. A. Prasad, A. Nürnberger

#1086 A Study on the Impact of Neurofeedback in EEG Based Attention-driven Game

Kavitha P Thomas (SG), Vinod Achutavarrier Prasad (SG)

Multi-disciplinary study of human computer interaction has provided significant impact in the fields of neural engineering, cognitive neuroscience, rehabilitation and brain-computer interaction. This paper evaluates the impact of neurofeedback in the context of a simple computer game controlled by attention based brain signals. The designed game protocol requires the player to memorize a set of numbers displayed in a matrix format, and to correctly fill the matrix using his attention based brain patterns. Attention level of the player, quantified using sample entropy values of Electroencephalogram (EEG) signals, is the core control parameter of the game. A comparative study using a single neurofeedback group and 2 control groups (each group consists of 8 subjects) has been carried out to examine the impact of neurofeedback on enhancing attention score and cognitive skill in the context of the attention-driven game. Experimental results explicitly demonstrate the significance and usefulness of neurofeedback in EEG based games.

#1963 Individual Alpha Peak Frequency Based Features for Subject Dependent EEG workload classification

Wei Lun Lim (SG), Olga Sourina (SG), Lipo Wang (SG), Yisi Liu (SG)

The individual alpha peak frequency (IAPF) is an important biological indicator in Electroencephalogram (EEG) studies, with many research publications linking it to various cognitive functions. In this paper, we propose novel Power Spectral Density (PSD) alpha features based on IAPF to classify 2 and 4 levels of EEG multitasking workload data. When optimized IAPF was considered, a 1.55% and 1.56% increase in average accuracy for 48 subjects' data, with 35 and 33 subjects showing improvement was observed for 2 and 4 class cases respectively. This trend suggests that individual specific features are able to improve classification performance compared to generalized features for subject dependent cases. The proposed features, which incorporates the biological meaning of the IAPF and provides subject specific information, can be considered as a viable alternative to the general alpha power feature when designing novel subject dependent feature sets for BCI workload recognition applications.

#2008 Biometric Identification of Persons Using Sample Entropy Features of EEG During Rest state

Kavitha P Thomas (SG), Vinod Achutavarrier Prasad (SG)

Biometric recognition of persons using brain waves has been identified as an attractive topic of research today. Existing popular biometric modalities of face, finger prints and voice signals are vulnerable to various kinds of attacks and spoofing techniques, whereas the emerging biometric trait extracted from brain wave is expected to act as an ideal biometric feature offering high degree of uniqueness, stability and universality. This paper analyses the efficacy of the complexity of Electroencephalogram (EEG) signals recorded during rest state for recognizing individuals from a publicly available EEG dataset consisting of 109 subjects. Sample entropy features extracted from delta, theta, alpha, beta and gamma bands of 64 channel EEG have been evaluated for subject-identification in the proposed system. It is found that beta band entropy has the highest inter-subject variability. Based on a Mahalanobis distance based classifier, beta entropy gives an average correct recognition rate of 98.31%. It has also been observed that concatenation of entropy features with power spectral density (PSD) values improves the system performance. Further analysis is essential to investigate the stability of results over time and to optimize the recognition performance at a reduced number of channels.

#2255 Predicting decision accuracy and certainty in complex brain-machine interactions

Victor Shih (US), Ludan Zhang (US), Christian Kothe (US), Scott Makeig (US), Paul Sajda (US)

A promising application of brain machine interfaces (BMIs) is predicting user cognitive state, particularly in complex and demanding scenarios, so that automation can dynamically and adaptively adjust task parameters to optimize joint human-machine performance. In this paper we analyze neural, physiological and behavioral data recorded during a complex two-person crew station" task and investigate whether these measures provide information for inferring user decision state. Specifically, we investigate how measures of EEG, pupil dilation, heart rate and response time, can be fused to infer decision confidence and accuracy in two side-tasks occurring throughout a three hour experimental session. One side-task is an auditory task, the other a visual task, both occurring within the context of the crew station scenario (auditory alert and a visual satellite map N-back task). We find that the best prediction performance always fuses EEG and pupil dilation measures, with results yielding between 70%-75% accuracy with respect to whether the subject(s) will skip making the decision (i.e. have high uncertainty) or whether he/she makes an error. Interestingly, the results suggest a possible mechanistic explanation for the utility of the fused measures, specifically the interaction between the locus coeruleus (LC), whose activity is linked to arousal state and can be inferred from pupil dilation, and the anterior cingulate (ACC), which has been linked to decision formation, and monitoring and whose activity is typically measured via EEG. In general, our results demonstrate the potential in using fused neuro/physio measures to infer and track human operator decision uncertainty during demanding complex tasks, possibly enabling BMIs to eventually be employed as "cognitive orthotics" for improving man-machine interaction and performance.

#2281 A Robust Interval Type-2 based BCI System

Ankit Das (SG), Suresh Sundaram (SG), Narasimhan Sundararajan (SG)

This paper presents a BCI system which addresses the key problems of robust feature extraction, non-stationarity and subject-specific spectral filter selection. It employs the Robust Common Spatial pattern (RoCSP) feature extraction algorithm which eliminates trials affected by artifacts and discards redundant channels to improve the robustness of the CSP algorithm. Next, it handles the non-stationarity in EEG signals using the Self-Regulated Interval Type-2 Neuro-Fuzzy Inference System (SRIT2NFIS). It uses the input features generated by the RoCSP algorithm and handles the non-stationarity as uncertainty using the interval type-2 fuzzy sets in the antecedent of fuzzy rules. A five layered modified Takagi-Sugeno-Kang interval type-2 fuzzy inference mechanism forms the structure and the learning algorithm uses a self-regulatory mechanism. Further, the SRIT2NFIS classifier is used to find the desired spectral filters by eliminating those frequency bands that do not affect the classification performance. The performance of the proposed system has been evaluated using two publicly available BCI competition data sets and compared with other existing algorithms like FBCSP, DFBCSP and BSSFO. The results indicate improved performances of the proposed algorithm. Finally, the proposed system is employed to control the movement of a quadcopter.

BMI Papers XI – BMI for Motor/Cognitive Rehabilitation and Assistance (II) (BMI Workshop Special Session XI)

Organizer: R. Chavarriaga
October 12 (Wednesday), 11:00-12:30, InterContinental Budapest, Panorama V
Session Chairs: R. Chavarriaga, S. Kleih

#1643 SSVEP Based BMI for a Meal Assistance Robot

Chamika Janith Perera (LK), Isira Naotunna (LK), Chameera Sandaruwa, (LK), R.A.R.C Gopura (LK), Thilina Dulantha Lalitharatne (LK)

Meal assistance robots provide disabled individuals the access to one of the important activities in daily living, self-feeding. This paper proposes a Steady State Visually Evoked Potential (SSVEP) based Brain Machine Interface (BMI) for controlling of a meal assistance robot. In the proposed system, the user has the facility to select any solid food item that he would like to eat from 3 different bowls just by looking at the respective LED matrices blinking at different frequencies. The generated SSVEP signals while looking at the LEDs are extracted from EEG signals acquired using OpenBCI EEG signal acquisition system. Extracted SSVEP signals are used to identify the intention of the user and subsequently the detected intentions are used to operate the meal assistant robot. Experiments are carried out to validate the system and results indicate the effectiveness of the proposed method.

#1841 Comparison of Hand and Forearm Muscle Pairs in Controlling of a Novel Myoelectric Interface

Jessica Barnes (GB), Matthew Dyson (GB), Kianoush Nazarpour (GB)

With commercial prosthetic hands, executing some everyday movements, for example, concurrent grasp and bending of the wrist to pick up an object from a high shelf, is very challenging. We hypothesised that after the loss of the hand, the flexibility of the nervous system enables prosthesis users to bypass the innate biomechanical constraints on upper-limb muscles and joints. We show that users are able to learn to operate a myoelectric-controlled interface by flexibly contracting pairs of hand and forearm muscles. The use of these novel activity patterns can have a transformative effect on the control of future prosthetic hands.

#1850 The Temporal Limits of Agency for Reaching Movements in Augmented Virtuality

Guillermo Roman Bernal (US), Oliver Alan Kannape (GB)

The sense of agency (SoA) describes the feeling of being the author and in control of one's movements. It is closely linked to automated aspects of sensorimotor control and understood to depend on one's ability to monitor the details of one's movements. As such SoA has been argued to be a critical component of self-awareness in general and contribute to presence in virtual reality environments in particular. A common approach to investigating SoA is to ask participants to perform goal-directed movements and introducing spatial or temporal visuomotor mismatches in the feedback. Feedback movements are traditionally either switched with someone else's movements using a 2D video-feed or modified by providing abstracted feedback about one's actions on a computer screen. The aim of the current study was to quantify conscious monitoring and the SoA for ecologically valid, three dimensional feedback of the participants' actual limb and movements. This was achieved by displaying an Infra-Red (IR) feed of the participants' upper limbs in an augmented virtuality environment (AVE) using a head-mounted display (HMD). Movements could be fed back in real-time (46ms system delay) or with an experimental delay of up to 570ms. As hypothesized, participant's SoA decreased with increasing temporal visuomotor mismatches ($p<.001$), replicating previous findings and extending them to AVEs. In-line with this literature, we report temporal limits of 222±60ms (50% psychometric threshold) in N=28 participants. Our results demonstrate the validity of the experimental platform by replicating studies in SoA both qualitatively and quantitatively. We discuss our findings in relation to the use of virtual and mixed reality in research and implications for neurorehabilitation therapies.

#2286 Classification of Gait from EEG Using Inverse Brain Mapping

Lea Hehenberger (AT), Martin Seeber (AT), Reinhold Scherer (AT)

Long-term impairment, disability and handicap are major issues after stroke. A wide range of interventions have been developed that aim to promote motor recovery in affected persons. High-intensity and task-specific training protocols show promising results. A better understanding of brain functioning in the context of motor learning and motor control may help to further improve rehabilitation outcome. Mobile brain imaging has brought advances that led to the development of models that characterize different aspects of the cortical involvement in movement. We are interested in translating those findings into online applications and lay a basis for novel rehabilitation interventions. In this paper, we use a model of gait consisting of two parameters: The state of walking (compared to upright standing) and the dynamics of the movement, i.e. the gait cadence. To this end, we perform mobile electroencephalography (EEG) measurements combined with inverse brain imaging and time-frequency analyses optimized for online application.

#2415 Imagined 3D Hand Movement Trajectory Decoding from Sensorimotor EEG Rhythms

Attila Korik (GB), Ronen Sosnik (IL), Nazmul H. Siddique (GB), Damien Coyle (GB)

Reconstruction of the three-dimensional (3D) trajectory of an imagined limb movement using electro-encephalography (EEG) poses many challenges. However, if achieved, more advanced non-invasive brain-computer interfaces (BCIs) for the physically impaired could be realized. The most common motion trajectory prediction (MTP) BCI employs a time-series of band-pass filtered EEG potentials for reconstructing the 3D trajectory of limb movement using multiple linear regression (mLR). Most MTP BCI studies report the best accuracy using low delta (0.5-2Hz) band-pass filtered EEG potentials. In a recent study, we showed spatiotemporal power distribution of theta (4-8Hz), mu (8-12Hz), and beta (12-28Hz) EEG frequency bands contain richer information associated with movement trajectory. This finding is in line with the results in the extensive literature on traditional sensorimotor rhythm (SMR) based multiclass (MC) BCI studies, which report the best accuracy of limb movement classification using power values of mu and beta frequency bands. Here, we show the reconstruction of actual and imagined 3D limb movement trajectory with an MTP BCI using a time-series of bandpower values (BTS model). Furthermore, we show the proposed BTS model outperforms the standard potential time-series model (PTS model). The BTS model yielded best results in the mu and beta bands ($R\sim0.5$ for actual and $R\sim0.2$ for imagined movement reconstruction) and not in the low delta band, as previously reported for MTP studies using the PTS model. Our results show for the first time how mu and beta activity can be used for decoding imagined 3D hand movement from EEG.

BMI Papers XII – Multi-modal Brain Computer Interface and Physiological Computing (BMI Workshop Special Session XII)

Organizer: V. A. Prasad
October 12 (Wednesday), 11:00-12:30, InterContinental Budapest, Ballroom I
Session Chairs: Sadasivan P., A. Stoica

#1620 Improved target recognition response using collaborative brain computer interfaces

Adrian Stoica (US), Kyongsik Yun (US)

The benefit of using collaborative brain computer interfaces in improving human response in visual target recognition tests was investigated. We used an EEG dataset by Delorme et al. 2004, created from recordings using 32-channel EEG system. The 14 participants performed a go/no-go categorization task on natural photos with animals, defined as targets, and non-animal distractors, presented very briefly. First, we compared the two evoked responses between the target and distractor images and determined that the P300 response was significantly higher in the target images than in the distractor images. Second, we calculated and compared the classification accuracy using one, two, and three EEG signal sets. We applied linear support vector machine with 5-fold cross validation. Compared to the results of a single brain prediction (79.4%), the overall accuracy of two and three brains prediction was better (89.3% and 88.7% respectively). Furthermore, the time to achieve the 90% accuracy was significantly faster when using EEGs from two and three brains (100ms) than that of one brain (230ms). These results bring supporting evidence to the hypothesis that one can achieve higher levels of perceptual and cognitive performance by leveraging the power of multiple brains through collaborative brain computer interfaces.

#2038 Inactive-State Recognition from EEG Signals and its Application in Cognitive Load Computation

Rahul Gavas (IN), Rajat Das (IN), Pratyusha Das (IN), Debatri Chatterjee (IN), Aniruddha Sinha (IN)

Extraction of desirable information from electroencephalogram signals require same level of active involvement from the participants throughout the entire duration of the task. However, this is hard to attain due to environmental, personal and internal factors including thought processes. This poses a major challenge in realizing accurate evaluation of mental workload. This study is aimed at detection of the inactive mental states of the participant during an experimental task. Conventionally cognitive load is computed with respect to the baseline period. Here a novel approach is adopted based on the detection of most inactive mental state during the rest period. It is observed that alpha rhythms (8 – 12 Hz) are dominant than theta rhythms (4 – 7 Hz) during the rest state and this information is used in determining the most inactive mental states. Galvanic skin response (GSR) is also analyzed for the same purpose to validate the decoded mental state from the brain signals. Results indicate that the proposed approach of inactivity detection, improves the overall accuracy of detection of cognitive load by 15.57%.

#2486 Optical EEG (OEEG): A Novel System Towards Portable Real-Time Brain-Computer Interfacing

Ehsan Kamrani (CA)

Typical brain-computer interfaces are mainly based on the monitoring of neural activities using electroencephalogram. However, in order to track and translate the human brain activities more accurate and in real-time, monitoring the hemodynamic activities of the brain is also necessary. Here we've introduced a new technique towards monitoring both the neural and the hemodynamic activities of the brain using a single portable device, for more accurate and real-time brain-computer interface applications.

#1962 An Investigation of Annotation Smoothing for EEG-based Continuous Music-emotion Recognition

Nattapong Thammasan (JP), Ken-Ichi Fukui (JP), Masayuki Numao (JP)

As emotional responses of a human to stimuli could evolve over the course of time, continuous emotion reporting is essential for the construction of a computational model to capture the temporal evolution of the human emotions. However, continuous emotion assessment is confronting various challenges, especially when using the continuous arousal-valence space. Manipulating emotion annotation data prior to performing emotion recognition is, therefore, necessary. In this paper, we present a study of applying three different signal filtering techniques to smooth annotation data; moving average filter, Savitzky-Golay filter, and median filter. We performed experiments of arousal and valence recognition in music listening tasks employing signals from electroencephalogram (EEG). Fractal dimension approach was adopted to extract informative features from brain dynamics and emotional states were then derived by classification and regression techniques. Our empirical results suggested the promise of the moving average filter that could enhance the performance of emotion classifying and tracking.

BMI Papers XIII – Brain and Human-Machine Interaction (BMI Workshop Special Session XIII)

Organizers: V. A. Prasad, S-W. Lee, R. Chavarriaga
October 12 (Wednesday), 11:00-11:45, InterContinental Budapest, Ballroom II
Session Chairs: T. Bonaci, R. Kozma

#1190 Online Eye State Prediction from EEG Data Using Deep architectures

Tharun Reddy (IN), Laxmidhar Behera (GB)

In the past decade, improvements in the production of in-expensive PC equipment and software has permitted more refined real-time signal processing in BCI systems. In the literature, Deep learning concepts have not been applied to EEG data analysis in a systematic manner. This paper applies various existing Deep learning architectures and algorithms for the classification of EEG data applied to eye state detection. The deep learning based classifier systems presented in this work are comparable to the state of the art classifiers devised by Roesler and Suenderman (2013), and Cameron et al.(2015). The goal of this work is to construct a system producing accuracies comparable to Roesler's K* classifier, Cameron et al. 's (RRF+K*) classifiers and at the same time providing enough speed to be used in an online BCI framework. In order to meet the constraints, following architectures were designed: A Multi layered neural network with ReLU and drop-out, deep belief networks based unsupervised learning, drop-out masks on deep neural networks. Specifically, we compare our results with K*, RRF, (K*+RRF), ada(RJ48F) classifiers. Also an in-depth analysis of binary class features has been done using t-SNE based visualizations while fitting elliptical contours to the features. Prior research suggests that instance-based/lazy learners like the K* algorithm are likely to be too slow to be used in a BCI framework, with ada(RJ48F) model performing decently well. But our chosen deep neural network architectures produce higher classification accuracies and have lower convergence times making them even faster within the time specifications of real-time classification and control applications.

#1549 Frequency Detection for SSVEP-Based BCI using Deep Canonical Correlation Analysis

Hanh Thi Vu (KR), Bonkon Koo (KR), Seungjin Choi (KR)

Canonical correlation analysis (CCA) has been successfully used for extracting frequency components of steady-state visual evoked potential (SSVEP) in electroencephalography (EEG). Recently, a few efforts on CCA-based SSVEP methods have been made to demonstrate the benefits for brain computer interface (BCI). Most of these methods are limited to linear CCA. In this paper consider a deep extension of CCA where input data are processed through multiple layers before their correlations are computed. To our best knowledge, it is the first time to apply deep CCA (DCCA) to the task of frequency component extraction in SSVEP. Our empirical study demonstrates that DCCA extracts more robust feature, which has about 27% higher signal to noise ratio (SNR) compared to those of CCA, and it results in better performance in classification with the averaged accuracy of around 91%.

#2231 Exocortical Cognition: Heads in the Cloud

Stuart Mason Dambrot (US)

From a neurocentric perspective, H. sapiens-generated technology can be described as our neocortex – primarily the prefrontal and sensorimotor areas – augmenting our physiological cognitive, perceptual, and movement-generating structures by projecting itself into the external environment. In this context, the emerging capability of neuroprosthetics to directly augment neurocognitive function presents a unique and highly promising scientific and technological undertaking, in that it (1) suggests the possibility of dramatically increasing cognitive function on a species-wide basis, and (2) is universally applicable to the enhanced ideation, investigation and comprehension of all areas of inquiry. Here I propose Exocortical Cognition (ECC) – a transdisciplinary augmented cognition framework based on a review of the literature, accelerating progress in and convergence of a range of independent areas of science and technology, and the application of technology forecasting techniques. If realized, Exocortical Cognition would significantly enhance human cognitive function and memory capacity while bridging the often-presumed gap between human and future machine intelligence.

BMI Papers XIII – A Tribute to Walter J. Freeman (BMI Workshop Special Session XIII)

Organizers: J. Carmena, R. Kozma, and J. Principe
October 12 (Wednesday), 11:45-12:30, InterContinental Budapest, Ballroom II
Session Chairs: J. Carmena, R. Kozma, J. Principe

#2363 Mass Action in Brains and Computers – A Tribute to Walter J. Freeman

Robert Kozma (US)

This contribution presents a brief review of experimental and theoretical approaches to brain dynamics, including concepts describing the unity of brain, mind, and body. We dedicate this essay to the memory of Walter J. Freeman, III, with a focus on his pioneering work in the past 60 years establishing the new field of computational neuroscience, including mass action in the nervous system, field theories of cognition and intelligence, and his quest towards inventing novel engineering approaches for brain-machine interfaces.

BMI Papers XIV – Machine Learning Methods for Brain-Computer Interfacing (II) (BMI Workshop Special Session XIV)

Organizer: R. Chavarriaga
October 12 (Wednesday), 11:00-12:30, Sofitel Budapest Chain Bridge, Bellevue 2
Session Chairs: D. Wu, B. Lance

#1649 PNN for EEG-based Emotion Recognition

Jianhai Zhang (CN), Ming Chen (CN), Sanqing Hu (CN), Cao Yu (US), Robert Kozma (US)

The effort to integrate emotions into human-computer interaction (HCI) system has attracted broad attentions. Automatic emotion recognition enables the HCI to become more intelligent and user friendly. Although numerous studies have been performed in this field, emotion recognition is still an extremely challenging task, especially in real-world practice usage. In this work, probabilistic neural network (PNN) , with advantage of simple, efficient, and easy to train, was employed to recognize emotions elicited by watching music videos from scalp EEG. The publicly available DEAP emotion database was used to validate our algorithms. The powers of 4 frequency bands of EEG were extracted as features. The results show that the mean classification accuracy of PNN is 81.21% for valence (≥5 and <5) and 81.26% for arousal(≥5 and <5) across 32 subjects, similar with the results of SVM. In addition, they demonstrate that higher frequency bands (beta and gamma) play more important role in emotion classification than lower ones (theta and alpha). For the purpose of practical emotion recognition system, we proposed a ReliefF-based channel selection algorithm to reduce the number of used channels for convenience in practical usage. The results show that while using PNN, the 98% of the maximum classification accuracy can be obtained with only 9 (for valence) and 8 (for arousal) best channels, however, 19 (for valence) and 14 (for arousal) channels are needed while using SVM.

#1928 A Separability Marker Based on High-Dimensional Statistics for Classification Confidence Assessment

Nathalie Therese Helene Gayraud (FR), Nathanael Foy (FR), Maureen Clerc (FR)

This work provides a theoretical analysis framework for features that belong to the high dimensional Riemannian manifold of symmetric positive definite matrices. In non-invasive EEG-based Brain Computer Interfaces, such as the P300 speller, these are sample covariance matrices of the epoched EEG signal, that are classified into two classes. An analysis of the class shape on the manifold is performed, and the level the separability of the two classes is evaluated. The main contribution is a method that appends a confidence marker to the prediction of a binary classifier whose decision function is based on the comparison of Riemannian distances, called the SM-confidence method.

#2114 Alternative CSP approaches for multimodal distributed BCI data

Stephanie Brandl (DE), Klaus-Robert Müller (DE), Wojciech Samek (DE)

Brain-Computer Interfaces (BCIs) are trained to distinguish between two (or more) mental states, e.g., left and right hand motor imagery, from the recorded brain signals. Common Spatial Patterns (CSP) is a popular method to optimally separate data from two motor imagery tasks under the assumption of an unimodal class distribution. In out of lab environments where users are distracted by additional noise sources this assumption may not hold. This paper systematically investigates BCI performance under such distractions and proposes two novel CSP variants, ensemble CSP and 2-step CSP, which can cope with multimodal class distributions. The proposed algorithms are evaluated using simulations and BCI data of 16 healthy participants performing motor imagery under 6 different types of distraction. Both methods are shown to significantly enhance the performance compared to the standard procedure.

#2361 A Hybrid ICA - Wavelet Transform for Automated Artefact Removal in EEG-based Emotion Recognition

Alain Desire Bigirimana (GB), Nazmul H. Siddique (GB), Damien Coyle (GB)

Removing artefacts from electroencephalographic (EEG) recordings normally increases their low signal-to-noise ratio and enables more reliable interpretation of brain activity. In this paper we present an evaluation of an automatic independent component analysis (ICA) procedure, a hybrid ICA - wavelet transform technique (ICA-W), for artefact removal from EEG correlated to emotional-state. Spectral and statistical features were classified with support vector machines (SVM) to assess the performance of ICA-W against the regular ICA, in terms of the accuracy of classifying emotional states from EEG. Accuracies on data from 14 subjects are reported and the results indicate that ICA-W performs better than traditional ICA in statistical and wavelet based features whilst the best overall performance is achieved when combining ICA-W with statistical features with an average accuracy across subjects of 74.11% for classifying four categories of emotion. ICA-W is therefore demonstrated to enhance EEG-based emotion recognition applications in terms of performance and ease of application.

#2381 Superposition model for steady state visually evoked potentials

Cardona Jaiber (CO), Caicedo Eduardo (CO), Wilfredo Alfonso (CO), Ricardo Chavarriaga (CH), José del R. Millán (CH)

Steady State Visually Evoked Potentials (SSVEP) are signals produced in the occipital part of the brain when someone gaze a light flickering at a fixed frequency. These signals have been used for Brain Machine Interfacing (BMI), where one or more stimuli are presented and the system has to detect what is the stimulus the user is attending to. It has been proposed that the SSVEP signal is produced by superposition of Visually Evoked Potentials (VEP) but there is not a model that shows that. We propose a model for a SSVEP signal that is a superposition of the response due to the rising and falling edges of the stimulus and that can be calculated for different frequencies. We fixed the model for 4 subjects that gazed stimuli in the frequencies of 9Hz, 11Hz, 13Hz and 15Hz, and duty-cycles of 20%, 35%, 50%, 65%, and 80%. Since the phases of SSVEP signals are stable over the time, these were used to fix the model, without the amplitude; however, signals of scattered phases were discarded. The model parameters were found using the Oz electrode signals and a genetic algorithm. The mean absolute error (MAE) between the measured phase and the obtained one was calculated for each subject (named S1, S2, S3, and S4). The model was fixed for the subjects in the fundamental frequencies, just two of them in the second harmonic, and one in the third harmonic. We obtained a maximum MAE for 3 subjects (S1, S2, and S4) in the fundamental frequencies at 0.30 rad and one of them (S2) with 0.21 rad in the second harmonic. The last one (S3) signals show poor results with a MAE between 0.46 rad and 1.79 rad by including fundamental frequencies, and second and third harmonics. The results show similarities among the different model parameters such that it suggests that a general model could be obtained. We fixed the model for 4 subjects that gazed stimuli in the frequencies of 9Hz, 11Hz, 13Hz and 15Hz, and duty-cycles of 20%, 35%, 50%, 65%, and 80%. Since the phases of SSVEP signals are stable over the time, these were used to fix the model, without the amplitude; however, signals of scattered phases were discarded. The model parameters were found using the Oz electrode signals and a genetic algorithm. The mean absolute error (MAE) between the measured phase and the obtained one was calculated for each subject (named S1, S2, S3, and S4). The model was fixed for the subjects in the fundamental frequencies, just two of them in the second harmonic, and one in the third harmonic. We obtained a maximum MAE for 3 subjects (S1, S2, and S4) in the fundamental frequencies at 0.30 rad, and one subject (S2) of them got 0.21 rad in the second harmonic. The last one (S3) signals show a poor performance with a MAE between 0.46 rad and 1.79 rad by including fundamental frequencies, and second and third harmonics. The results show similarities among the different model parameters such that it suggests that a general model could be obtained.

BMI Papers XV – Sensor Systems for BMI and Prosthetics (BMI Workshop Special Session XV)

Organizers: V. A. Prasad, S-W. Lee, R. Chavarriaga
October 12 (Wednesday), 11:00-12:30, Sofitel Budapest Chain Bridge, Bellevue 3
Session Chairs: S-W. Lee, T. Zander

#1528 Variable admittance control in pHRI by measuring muscle co-activation with EMG

Fotios Dimeas (GR), Stavros Grafakos (GR), Nikos Aspragathos (GR)

In this paper, the co-activation level of the arm muscles is used as an indication of the end-point stiffness for improving human-robot cooperation. A variable admittance controller is proposed to adjust the virtual damping in real time by measuring the operator's muscle activation by means of surface EMG. An experimental user study is conducted that simulates both high accuracy and fast transition movements, involving human-robot interaction with a 7-DOF LWR serial manipulator. The proposed method is compared to constant admittance and is evaluated in terms of movement accuracy, execution time, and the operator's energy consumption. The results demonstrate that there is a significant reduction of the operator's effort and an improvement of the cooperative motion accuracy.

#1658 Patient Simulator Using Wearable Robot to Estimate the Burden of Knee-Osteoarthritis Patients during Sitting-down and Standing-up Motions

Ryu Kubo (JP), Ayaka Hirukawa (JP), Shogo Okamoto (JP), Naomi Yamada (JP), Yasuhiro Akiyama (JP), Yoji Yamada (JP)

The estimation of the physical burdens from which people with motor impairment suffer helps us establish welfare techniques comprising personal care equipment and assessment of critical risks, such as fall risks. However, the involvement of actual patients in the evaluation and development of this equipment is costly and involves the exposure of patients to long and exhausting experiments. To solve this problem, we developed a robot wearable by a healthy person and the associated control algorithm to simulate typical motions of patients with knee osteoarthritis, which is a common symptom for the elderly and causes pain during movement. To estimate the physical burdens inflicted by knee malfunctions, we computed the knee flexion and extension moment of the simulated patient during the standing-up and sitting-down motions. The moments, estimated under certain conditions, are qualitatively consistent with those considered clinically, which corroborates the validity of our patient simulation techniques.

#2116 Control of Artificial Human Finger using Wearable Device and Adaptive Network-Based Fuzzy Inference System

Seyed Reza Larimi (CA), Hojatollah Rezaei Nejad (CA), Mina Hoorfar (CA), Homayoun Najjaran (CA)

This paper demonstrates a new approach for the use of multiple strain sensors on a wearable flexible finger band to measure the posture and movement of a human finger accurately. The system is further developed to repeat the human finger motion on a robotic finger. Here, we used adaptive network-based fuzzy interface system (ANFIS) to relate the strain sensor readings to human finger posture and motion. The input and output measurements used to train ANFIS are obtained from the strain sensors of the wearable platform and a 3 degree of freedom (DOF) exoskeleton testbed, respectively. The ANFIS model is then used to predict human finger posture and motion directly from the strain sensors installed on the finger band. We made additional experiments and generated testing data using the exoskeleton testbed to verify the ANFIS model. Finally, we demonstrate that the robotic finger closely follows the human finger motion by reading the wearable finger band output and calculating the posture and motion parameters in real time.

BMI Papers XVI – Real World Applications of Brain Computer Interface Systems (III) (BMI Workshop Special Session XVI)

Organizer: V. A. Prasad
October 12 (Wednesday), 14:00-15:30, InterContinental Budapest, Panorama I
Session Chairs: V. A. Prasad, J. Dauwels

#2485 EEG based Biometric Recognition Using Subject-Specific Alpha Peak Frequency and Delta Band Power

Kavitha P Thomas (SG), Vinod Achutavarrier Prasad (SG)

Brain activities are inherently determined by a person's unique pattern of neural pathways and are closely associated with his/her specific personality traits. Brain activity, recorded by electroencephalogram (EEG), has recently been identified as potential candidate in future generation biometric systems. In this paper, a biometric identification system is proposed combining subject-specific alpha peak frequency, peak power and delta band power values to form representative feature vectors as well as discriminative templates. In order to study the inter-subject and intra-subject variabilities of the EEG patterns, a public dataset of EEG signals recorded from 109 healthy subjects during eyes open/closed (EO/EC) relaxed rest states has been analyzed. Employing simple similarity measurements based on correlation and distance measures of the test EEG sequences in comparison with the template vectors, an average recognition rate of up to 90% has been achieved using a set of selected 19 electrodes. The achieved results explicitly show the usefulness of combining subject-specific alpha and delta bands in future biometric recognition systems.

#2494 EEG hyperscanning study of inter-brain synchrony during cooperative and competitive interaction

Justin Dauwels (SG), Sinha Nishant (SG)

Social cognition is the study of how people interact with each other in a social situation. An effective interaction would require higher degree of cognitive involvement between the participants and consequently, an enhanced synchrony between their neural mechanisms. In this study, twelve pairs of subjects interacted with each other via a cognitively engaging experimental paradigm in which they either competed or cooperated with each other for performing a task. While they were performing the task we incorporated electroencephalographic (EEG) hyperscanning techniques by simultaneously recording the EEG activities of the interacting subjects. We quantified these interactions by computing the inter-brain synchrony (IBS) and studied the changes in IBS under different experimental conditions. We found that the inter-brain synchrony between the subjects was significantly higher when they cooperated with each other as compared to the competitive scenario. Furthermore, we found that IBS was significantly enhanced when the subjects were physically separated i.e. they cooperated via an intranet network. In this work, we have demonstrated how EEG hyperscanning technique can be employed to study inter-brain synchronization under different conditions.

#2151 Spatial Filter Feature Extraction Methods for P300 BCI Speller: A Comparison

Eleni Chiou (DK), Sadasivan Puthusserypady (DK)

Brain Computer Interface (BCI) systems enable subjects affected by neuromuscular disorders to interact with the outside world. A P300 speller uses Event Related Potential (ERP) components, generated in the brain in the presence of a target stimulus, to extract information about the user's intent. Several methods have been proposed for spatial filtering and classification of the P300 components. In this study, xDAWN algorithm, Independent Component Analysis (ICA) and Principal Compo- nent Analysis (PCA) methods are used and evaluated based on the classification performance of two different classifiers, namely the Support Vector Machine (SVM) and Fisher's Linear Discriminant Analysis (FLDA). In addition, it is shown that the incorporation of some prior knowledge regarding the location of P300 elicitation on the scalp can reduce the computational load while maintaining or even improving the classification performance.

#1194 A Simple Action of Right Index Finger Induces Rubber Hand Illusion to Static Left Hand

Masayuki Hara (JP), Noriaki Kanayama (JP), Daisuke Yamaguchi (JP), Yuji Ishino (JP), Masaya Takasaki (JP), Takeshi Mizuno (JP)

The rubber hand illusion (RHI) is a bodily illusion that a fake rubber hand is felt as if it was one's own hand when both the hands are synchronously stimulated. Also, it is well-known that people can experience the RHI when the movements of the visible fake and invisible real hands are synchronized. However, underlying mechanism of the RHI and relationship between action and body ownership are still open questions. Based on the RHI paradigm, the present paper discusses how the agency of a body part affects the sense of body ownership at the other body part. In this study, we examined if a simple up-and-down action of right index finger induces the RHI to left hand which was kept still by using virtual reality and robotics technologies. Our experimental results indicated that the action of the right index finger allowed the embodiment of the virtual hands at both the right and left hands. This implies that only a simple action of a body part increases the sense of body ownership at the other body part.

#2097 A Novel Multimodal Gaze-Controlled Hindi Virtual Keyboard for Disabled Users

Yogesh Kumar Meena (GB), Hubert Cecotti (GB), KongFatt Wong-Lin (GB), Girijesh Prasad (GB)

Over the last decade, there has been a speedy an increase in the number of persons with mobility and speech impairments who require novel communication devices. Most of the recent works that have been carried out to focus on the Latin script; there is a lack of appropriate assistive devices for scripts that are specific to a country. In this paper, we propose a novel multimodal Hindi language virtual keyboard based on a menu selection with eight commands providing access to spell and type 63 different Hindi language characters along with other functionalities such as the delete command for corrections. The system has been evaluated with eight able-bodied individuals who performed a specially designed typing task. The spelling task has been achieved in three different modalities using: (i) a mouse, (ii) a portable eye-tracker, and (iii) a portable eyetracker combined with a soft-switch. The performance has been evaluated over the changes that occur with the use of each modality in terms of typing speed and information transfer rate (ITR) at both the command and letter levels for each subject. The average speed across subjects with mouse only, eye-tracker only, and eye-tracker with soft-switch were 17.12 letters/min, 10.62 letters/min, and 13.50 letters/min, respectively. The ITRs at the command and letter levels were about 67.58 bits/minute and 62.67 bits/minute, respectively, with only the eye-tracker option. Based on its robustness, the proposed system has the potential to be used as a means of augmentative communication for patients suffering from mobility and speech impairment, and can contribute to substantial improvement in their quality of life.

BMI Papers XVII – Recent Advances in BMI Speller (BMI Workshop Special Session XVII)

Organizers: S-W. Lee, B. Blankertz
October 12 (Wednesday), 14:00-15:30, InterContinental Budapest, Ballroom II
Session Chairs: S-W. Lee, B. Blankertz

#1415 Analysis of Steady State Visual Evoked Potential based on Viewing Distance Changes for Brain-Machine Interface Speller

No-Sang Kwak (KR), Dong-Ok Won (KR), Keun-Tae Kim (KR), Hee-Jin Park (KR), Seong-Whan Lee (KR)

Recently, steady-state visual evoked potential (SSVEP)-based brain-machine interface (BMI) speller systems have shown a great performance increase with high information transfer rate (ITR) and short response time. In previous BMI speller systems, however, users should utilize the systems at fixed viewing distance environment for evoking SSVEP signals because a variation of the SSVEP signals according to changes of viewing distance was not considered during system design process. For a real-world application of BMI speller, reliable speller systems which are robust to the various viewing distance environment are needed. In this study, hence, we investigate the effects of viewing distance on SSVEP by changing distance between a user and visual stimuli. Here, we used four visual stimuli which have different frequencies using LED monitor. In the subsequent analysis, we present classification results with several methods. Our analysis and results show a possibility that SSVEP under various viewing distance environment could be facilitated.

#1523 OpenBMI: A Real-Time Data Analysis Toolbox for Brain-Machine Interfaces

Min-Ho Lee (KR), Keun-Tae Kim (KR), Young-Jin Kee (KR), Ji-Hoon Jeong (KR), Seon-Min Kim (KR), Siamac Fazli (KR), Seong-Whan Lee (KR)

Recently, there has been an increased demand for Brain-Machine Interface (BMI) toolboxes for neuroscientifc research. In many BMI applications, speller systems can provide an efficient communication channel for users with disabilities. Here, we introduce an open-source BMI toolbox termed 'OpenBMI', which supports the various signal processing chains for common BMI paradigms, such as event-related potentials (ERPs) and steady-state visual evoked potentials (SSVEP). The OpenBMI framework consists of ready-to-use experimental paradigms, offline data analysis techniques, online feedback as well as evaluation modules. The data analysis modules provide essential pre-processing steps (segmentation, baseline correction, etc.) as well as signal processing algorithms such as temporal and spatial filtering, artifact rejection, among others. The experimental paradigms of ERP and SSVEP are available with fully open-sourced demo scripts. Users can easily modify or extend the demo scripts for their needs. In this article, the OpenBMI framework, its features as well as its future development plan is introduced.

#1793 How to identify the user specific stimulation frequencies for SSVEP-based BCI

Izabela Rejer (PL), Lukasz Cieszynski (PL)

The aim of this paper is to compare some approaches used for detecting user specific stimulation frequencies in terms of the number of detected Steady State Visual Evoked Potentials (SSVEPs). We performed our analysis with 6 subjects with respect to three factors: channels, time windows and harmonics/subharmonics used for power spectrum calculations. Results: 1. The best results across original channels and their combinations were obtained for O2 referenced to Pz and for the average of O2 and O1 referenced to Pz. 2. The length of time window (2, 5, or 10 seconds) did not have an influence on the average results. 3. The best results across the harmonics/subharmonics used for power spectrum correction were obtained when the first harmonic was added to the original power spectrum. 4. While with the best combination of all three factors (the average of O2 and O1 referenced to Pz; time window of 10 seconds; fundamental frequency + first harmonic in the power spectrum), we were able to detect 41% out of all 85 stimulation frequencies used in the survey, only 13% was detected with the worst combination (the O1 referenced to O2; time window of 2 seconds; fundamental frequency + first subharmonic in the power spectrum).

#2187 Notes on the Assessment of BCI-Driven Spellers

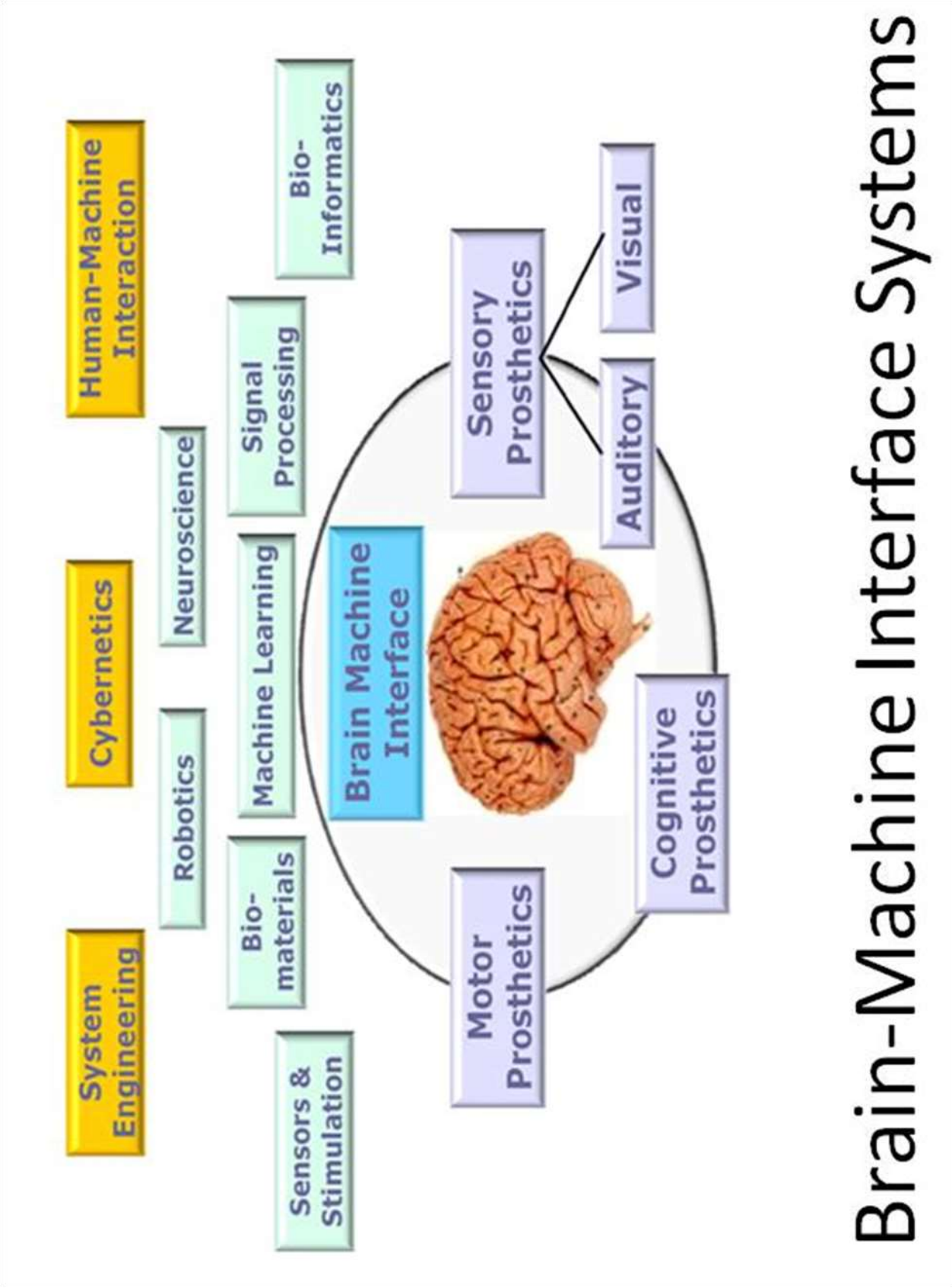
Benjamin Blankertz (DE), Matthias Treder (GB)

A Brain-Computer Interface (BCI) is a system that allows its user to control an application by real-time 'decoding' of brain signals. A fair comparison and evaluation of BCI systems from the literature is intricate due to the fact that different performance metrics are used. Many metrics draw on information theoretic approaches that model a communication channel in which the user has to code the message in order to make it error tolerant -- an unrealistic model for BCI. This contribution discusses how to measure and compare the performance of BCIs that are used for communication (so-called 'mental typewriters' or 'spellers'). We advocate a simple and intuitive metric: the number of symbols written in a certain amount of time, while accounting for the actions that have to be performed in order to correct errors that are based on misclassifications of the BCI system. It is discussed how this proposed measure differs from the widely used information transfer rate (ITR). Other aspects of comparing speller performances are cover as well, such as speed/accuracy trade-off, extrapolation to longer stimulation sequences and comparing systems with different sized vocabulary.

#2493 A comparison of face speller approaches for P300 BCIs

Christoph Guger (AT)

Brain-Computer Interfaces (BCIs) can provide users with communication, control, and other capabilities based on specific types of brain activity. In the "P300 BCI" approach, a user views a matrix containing letters or other characters and silently counts each time a target item flashes. Classically, characters flashed by briefly reversing color or other basic changes. Recent work has shown that the new "face speller" approach can improve P300 BCI performance. In this approach, each character changes to a human face during each "flash" instead of simply reversing color or other simple changes. The neural activity required to process the attended face, as well as other stimulus changes, may elicit more distinct evoked potentials that can improve classification. While the "face speller" has shown that face presentation may improve BCI performance, it raises the broader possibility that other stimulus changes could provide further performance improvements. The present study explored P300 BCI performance across four conditions. A control condition used "upturned" black and white stimuli that simply reversed color during each flash. Three other conditions explored different face conditions, varying color and the number of different faces presented during each flash. Accuracy was higher in all three face speller conditions than in the conventional "upturned" condition. Colored faces may yield higher accuracy than black and white faces.



Brain-Machine Interface Systems