Holistic Design Methodology for Automated Implementation of Human-in-the-Loop Cyber-Physical Systems

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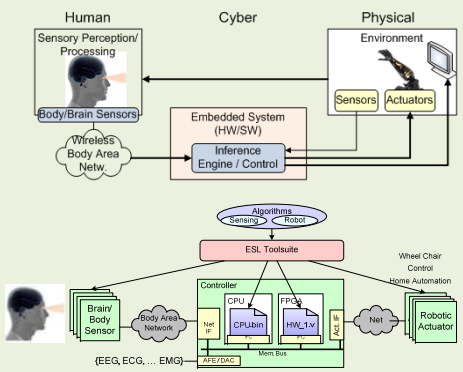
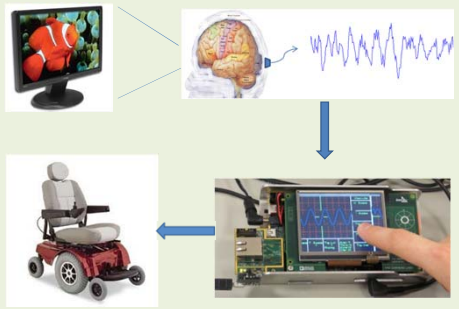


Objectives

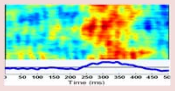
- Establish a holistic design framework that integrates physical environment modeling, providing an automated path from algorithm design to embedded implementation.
- Advance Body/Brain Computer Interface (BBCI) technology by incorporating context aware inference and learning of task-specific human intent estimation.
- Develop robotic actuators that operate robustly and semi-autonomously under uncertain aim (such as navigation) and environmental conditions.
- Design retargetable, reliable and efficient real-time communication framework integrating physically distributed components.
- Deliver an open framework and prototyping platform as an enabler for accelerated novel research for human-in-the-loop cyber-physical systems.



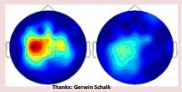
Context-aware BBCI Design

Typical Brain Signals Exploited in EEG-BCI Design

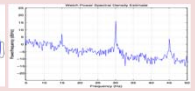
Visual or auditory evoked P300 response (ERP)

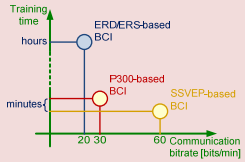


Motor imagery (MI) or other synchronization / dysynchronization activity in the motor cortex



Steady state visual evoked potentials (SSVEP)





SSVEP-BCI

- Exploits visual cortex response patterns observed due to periodic flickering of visual stimulus

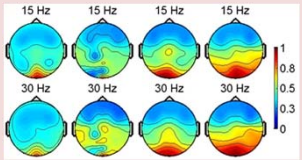
Frequency

- Temporal stimulus pattern is: 0101010101010…
- Different symbols have different bit presentation rates.
- Frequency resolution of PSD estimation imposes a limit.
- Artifacts and background brain activity overlap with stimulus response in Fourier domain.

PRBS

- Temporal stimulus pattern is ~: 111010100001000…
- Different symbols have different bit sequences.
- Number of distinct sequences imposes a limit.
- Codes are ultra-wideband. Narrow-band artifacts present a smaller problem.

Spatial distribution of single-channel correct classification probability among 4 m-sequences for 4 subjects, 15 & 30 bits/sec.



Rapid Prototyping of Human-in-the-Loop Systems

Algorithm

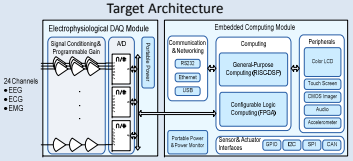
- Advances in algorithm design
  - Signal conditioning
  - Pattern detection
- Goal:
  - Real-time triage support
  - Augmentation
    - Intent inference
- Large divide between algorithm design and embedded implementation
  - Fall back on offline processing
  - No real-time interaction possible
    - Human reactions to measurements / intent detection cut

Gap

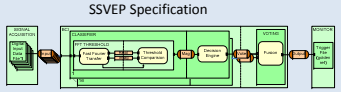
Technology

- Increasing capabilities of Multi-Processor System-on-Chip (MPSoCs)
- Increasing complexity
  - Feature demands
  - Production capabilities + Implementation freedom

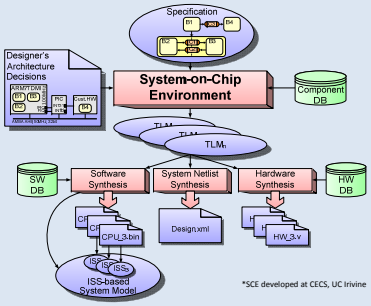
Target Architecture



SSVEP Specification



Design Flow



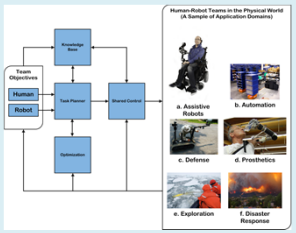
*SCE developed at CECS, UC Irivine

Robotic Assistive Technology

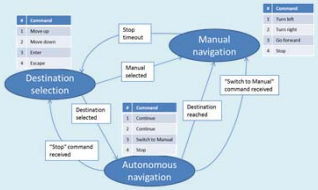
Objectives

- Design and validate shared control algorithms for a modular wheelchair,
- Design and control a modular, reconfigurable and compliant robotic arm
- Model proper autonomy levels for human-in-the-loop CPS and implement active control algorithms for robot motion coordination for effective and sensor-based mobile manipulation.

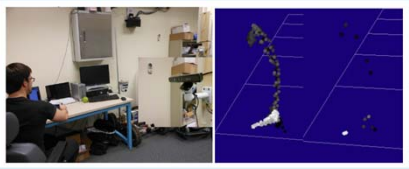
Shared Control in Human Robot Teams



State Flow of the BCI Controlled Autonomous Wheelchair



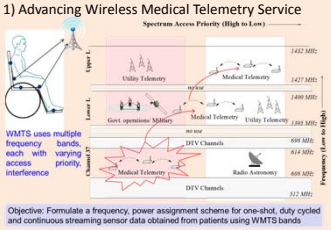
Task Space Analysis



An experimental task-space analysis to explore the design space for a self-feeding robot manipulator to maximize the manipulability measure in the regions of interest (i.e. near the table top) in robot workspace.

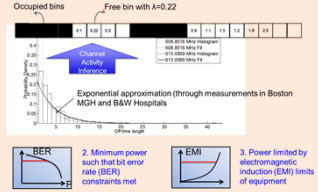
Wireless Body Area Networks

1) Advancing Wireless Medical Telemetry Service

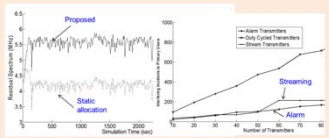


Objective: Formulate a frequency, power assignment scheme for one-shot, duty cycled and continuous streaming sensor data obtained from patients using WMTS bands

2) Algorithm Constraints

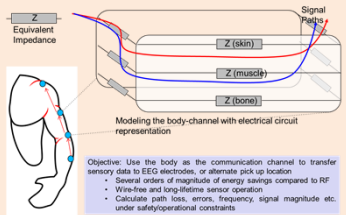


3) Results and References



- R. Doost-Mohammady, K. R. Chowdhury, "Enhancing Wireless Medical Telemetry Through Dynamic Spectrum Access", *IEEE ICC* **(best paper award)**, Canada, 2012.
- R. Doost-Mohammady, K. R. Chowdhury, "Transforming Healthcare and Medical Telemetry through Cognitive Radio Networks", *IEEE Wireless Communication Magazine*, August 2012.

4) Body Coupled Communication



Objective: Use the body as the communication channel to transfer sensory data to EEG electrodes, or alternate pick up location

- Several orders of magnitude of energy savings compared to RF
- Wire-free and long-lifetime sensor operation
- Calculate path loss, errors, frequency, signal magnitude etc. under safety/operational constraints