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

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Abstract

Our overarching goal is to develop a framework for design automation of cyber-physical systems that augment human-in-the-loop inference and interaction by complex systems operating at the interface of computation and physical environment. The population of functionally locked-in individuals, who are unable to interact with the physical world through movement and speech, would tremendously benefit from one such system, which could provide reliable, robust, and sufficiently agile interfaces to the cyber-physical environment for interaction, communication, and control.

Designing and implementing such complex cyber-physical systems is extremely challenging and time consuming as the composing disciplines are currently operating in isolation and sequentially: (a) design of cognitive intent detection algorithms using brain or other neurophysiological signals, (b) actuator and robotics design to realize the intended outcome or effect in the physical world, (c) distributed sensor and agent adaptations and associated efficient communication protocol considerations, and (d) efficient embedded systems implementations of these solutions. Even though toward a common goal, these disciplines acting independently leads to unnecessarily long design cycles and extended implementation times, hindering the opportunity to take advantage of cross-discipline optimizations. Consequently, assistive technologies evolve extremely slowly and always proposing sub-optimal solutions and implementations.

Utilizing advances in system-level design and design automation, we will develop a holistic methodology for the design and implementation of human-in-the-loop cyber-physical systems. In particular, we will:

- 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.

In result, the proposed work will significantly speed up the design of complex CPS. The availability of a holistic design methodology will enable tighter fusion of discipline-specific design principles allowing for cross-discipline optimizations. Consequently, this project supports cross-pollination of ideas across four currently disjoint disciplines, leading to otherwise not-achievable advances. Our work also establishes an open prototyping platform and a design framework for rapid exploration or novel human-in-the-loop application and therefore acts as an accelerator for novel research for a broad class of cyber-physical systems.

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