Towards a Modeling Framework for Shared Control Cyber Physical Systems

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It is evident that over the last decade, the emergence of research in cyber physical systems (CPS) in a very diverse set of domains has encouraged innovative approaches to complex problems and challenges. Because of their nature, with abstract elements in the cyber sphere and concrete objects in the physical environment, interactions within the CPS require design and analysis through different methods than traditional systems. An additional complexity arises from researchers using an entirely different language to describe the same core principle in a different domain. Ultimately, one of the goals of research in CPS should be to focus on a framework and associated methodologies to enable and encourage the cross-pollination of ideas, approaches, and solutions between the domains.

At the 2013 IEEE Systems, Man, and Cybernetics Conference held in Manchester, UK, a workshop was held on shared control where almost every system presented would be considered a CPS. Application domains included haptic control for more efficient deep sea exploration, control of multiple rovers in a space environment, assistive curve negotiation in vehicles, and assistive robotics to improve quality of life. Modeling these CPS is challenge within each domain because the systems are complex, information travels through many pathways within the system, information interfaces are not traditional, and the systems tend to be hybrid in nature with very asynchronous communication. As highlighted in the research literature, comparison of these systems is possible within the same application domain, but currently very difficult or impossible in some cases across different domains.

According to [1] the future of shared control CPS leverages transparent input interfaces, good context-aware models to enable human intent inference, a well-executed shared governance of the system, modularity/re-configurability, and distributed architectures. We posit that the lack of a framework that can effectively model cross-domain CPS implementations limits the ability of shared control CPS to leverage the concepts outlined above. Such a framework needs to be developed and designed to be generic enough to be functional in different application domains, but at the same time have specificity allowing the intricacies of specific implementations to be captured.

In addition, such a framework needs to be easily adaptable and extensible to grow as research thrusts push in different directions. The framework should be able to accommodate standard and non-traditional metrics that can be used to evaluate CPS and are relevant in cross-domain applications. Concepts such as trust between agents in the system, the performance of the system, the control effort required within the system, and efficiency of control need to be easily quantified and described within the framework. In addition to these interface-level metrics (metrics between subsystems within the CPS), metrics internal to the subsystems should be available to encourage system-level optimization and model-based control of these CPS. Complex intricacies in the systems can then be easily evident as opposed to being buried in the details and coupling of the individual subsystems.

The figure below shows the preliminary proposed framework that corresponds to the features outlined above. The framework is composed of several elements that we have identified to be common to CPS we are developing in space robotics, disaster response robotics, and assistive robotics: a knowledge base, action engine, robot control, human-robot interface, cloud engine, and operator interface. The framework is by no means complete, not all CPS will necessarily include each element, and will expand, consolidate, and change as our research progresses. The knowledge base stores possible approaches and algorithms that may be useful to the action engine which sets the task level behaviors of the robot or autonomous agents in the system. It should be noted that the robot does not need to be a robot in the traditional meaning of the word. Any autonomous agent would fit the framework as well. The robot control algorithms implement these task level behaviors. A human-robot interface defines the boundaries between the operator(s) through both the operator interface and cloud engine. The cloud engine can harness the power of additional human input, whether real through crowdsourcing or simulated through human interaction and inference models. The cloud engine can directly influence the operator interface.

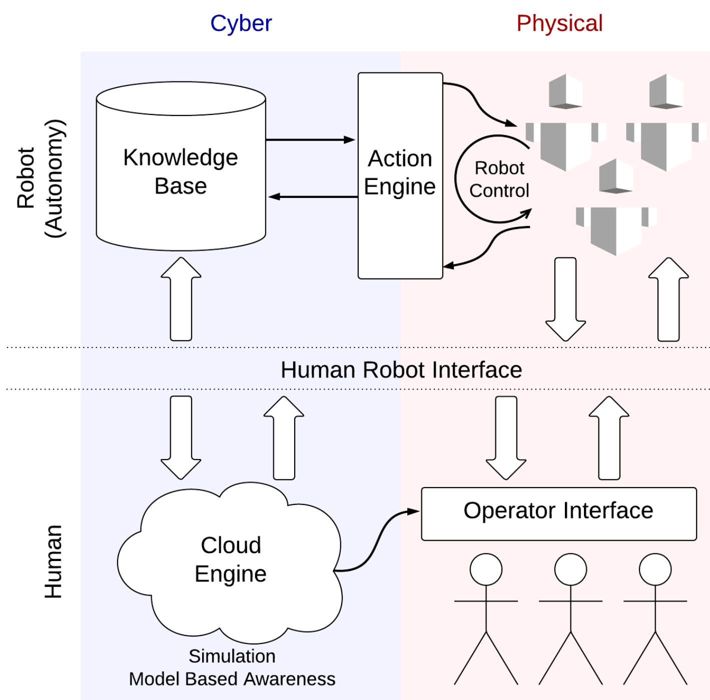

Figure 1 - The proposed framework to enable modeling of cross-domain cyber physical systems.

Despite the simple nature of the diagram, we feel this is a preliminary implementation of a very powerful approach to model CPS that has potential impacts across the whole range of application domains. It can enable the cross-pollination of ideas and approaches, the ability to compare and contrast ideas in common structure, and allow researchers to describe CPS in a common language. The framework allows us to compare the approaches we have taken in three very different domains at WPI: space robots, disaster response robots, and assistive robotics. Space exploration is in need of systems to allow heterogeneous teams of rovers to effectively explore unknown terrain with limited human interaction. Disaster robots, such as the ATLAS robot in the DARPA Robotics Challenge, need architectures to mitigate degraded communication links. Finally, assistive robotics meant to help people with disabilities need to make the most of information from slow and lossy interfaces. All three of these applications can be described within the proposed framework. Future work needs to focus on expanding the framework and integrating metrics to enable model-based control and optimization of CPS.

[1] Schirner, G.; Erdogmus, D.; Chowdhury, K.; Padir, T., "The Future of Human-in-the-Loop Cyber-Physical Systems," *Computer* , vol.46, no.1, pp.36,45, Jan. 2013