A Cyber Sensor Model for Cyber-Physical-Social Systems

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ABSTRACT

Engineering sustainable cyber-physical-social systems demand a transdisciplinary approach. Within an arbitrary domain, many systems, including those of the physical and cyber categories, may already be in-situ; however, heterogeneity permeates such systems, for example, differing protocols, data formats, among others. Heterogeneity is not a deliberate feature of an arbitrary system; rather, it is the cumulative result of pragmatic decisions that were made during design and is driven by many different factors, some of which may not be technological. Nonetheless, heterogeneity represents a critical obstacle for system designers as they seek to harness and integrate diverse system elements to deliver innovative services. This obstacle is acutely manifested in cyber-physical-social systems when collecting and fusing data for evidence-based decision-making; social and human-derived data exacerbate the problem. This paper proposes a programming model for fusing information sources in cyber-physical-social systems. The efficacy of the model is validated via a usability analysis.

KEYWORDS

Applied Software Engineering, Cyber-Physical-Social Computing, Human Factors, Programming Models

INTRODUCTION

Cyber-Physical Systems (CPSs) (Delicato et al., 2020; Liu et al., 2017) envisage a tight coupling between computing processes and the physical world. Engineering efficient, robust and secure CPSs pose many challenges; minor faults in design may result in catastrophic and tragic events in the physical world, as documented experiences with autonomous vehicles testify. Nonetheless, CPS are an indispensable and often invisible enabler of many services in the modern world. As the complexity of CPSs invariably increases, a need for more sophisticated models, methodologies and tools will be needed (Lee, 2015). For example, Intelligent CPSs (iCPSs) advocate embedding artificial intelligence techniques in the feedback loops for enabling decision-making in next-generation CPS (Vijayakumar et al., 2019). A complementary approach, that of Digital Twins (Rasheed et al., 2020), advocates constructing replicas of physical processes; in this way, more sophisticated models of reasoning and learning may emerge.

CPSs may leverage pre-existing cyberinfrastructures by incorporating them into their technology stack. The Sensor Web (Zhang et al., 2018) is an exemplar of such infrastructure; it enables programmatic access to networks of heterogeneous sensors for use in system development, sometimes in systems with global reach. Thus, when building CPSs, software engineers can call on an array of tried and trusted technologies such as Wireless Sensor Networks (WSNs), middleware, and Internet

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of Things (IoTs) along with a range of mature standards, for example, those of the Open Geospatial Consortium (OGC). The net result is that the CPSs concept has been demonstrated in a wide range of domains including environmental monitoring (Mois et al., 2016), landslide detection (Liu et al., 2019), smart agriculture (Liu et al., 2020), health (Ashutosh Sharma et al., 2019) and even space technologies (Akyildiz & Kak, 2019).

Cyber-Physical-Social Systems (CPSSs) are, in contrast to their CPSs peers, less-well developed. Such systems offer an intriguing vision – the intrinsic incorporation of the human dimension in a variety of facets into system operation. Such incorporation may be relatively passive, for example, data or information provision, or may involve active human-in-the-loop participation that enables human-automation symbiosis as envisaged by Industry 4.0 (Rauch et al., 2020). Just as CPSs may leverage the Sensor Web, a CPSS may likewise leverage the Social Web (Russell & Klassen, 2018). In practice, challenges with data collection arise, especially if a big data solution is envisaged. However, even within relatively constrained circumstances, difficulties arising from a lack of software engineering toolkits and the inherent complexity. This paper demonstrates that in viewing CPSSs as an extension of CPSs, rather than a singular paradigm in its own right, core technologies that underpin CPSs may be refactored and augmented to form an intuitive foundation for either or both paradigms.

This paper is structured as follows. A review of the state-of-the-art is presented in the next section. A model for a CPSS incorporating social web precepts is then proposed. An implementation of this model is then validated using a cohort of software engineers. After discussing the results of the evaluation, the paper is concluded.

BACKGROUND

Cyber-Physical computing is considered as the successor to embedded systems and WSNs that traditionally underpin pervasive computing research. Definitions of cyber-physical computing primarily focus on the technical integration of cyber and physical systems, focusing on the communication capabilities of cyber systems and the benefits and complexities of such integration (Bordel et al., 2018; Y. Liu et al., 2017). The human element of cyber-physical computing underpins the concept of cyber-physical world convergence. Such convergence results in a paradigm shift in which “real-world components interact with cyberspace via sensing, computing and communication elements” causing information to flow “from the physical to the cyber-world and vice-versa, adapting the converged world to human behavior and social dynamics” (Conti et al., 2012, p. 2). Such a view is consistent with the definition of CPSSs offered by other researchers. Wang (2010) defines CPSs as “the tight conjoining of and coordination between computational (or cyber) and physical resources” p. 85, and further defines Cyber-Physical-Social systems as being cyber-physical systems “tightly conjoined, coordinated and integrated with human and social characteristics”. Sheth et al. (2013) define physical-cyber-social computing as a paradigm that “encompasses a holistic treatment of data, information, and knowledge from the physical-cyber-social “worlds to integrate, correlate, interpret, and provide contextually relevant abstractions to humans” p. 78. Physical-Cyber-Social computing is viewed as a next-generation paradigm which builds on ‘cyber-physical systems’, ‘socio-technical systems’, and ‘cyber-social systems’. Such a view explicitly acknowledges the diversity of technologies and infrastructures that must be seamlessly integrated if the vision of CPSSs is to become a reality.

CPSSs are at a nascent stage of their development lifecycle; although prototype CPSSs are documented (see, for example, Zhang et al., 2018), nonetheless, best practice in design and implementation is non-existent. One approach advocates the use of pre-existing methodologies from embedded systems and CPSs; one example of this approach has produced a system-level design framework (Zeng et al., 2020). Likewise, Zhou et al. (2020) have proposed a virtualization architecture, augmented with an integrated framework of caching, computing and networking. Following a theme of software reuse, Wang et al. (2020) advocate a Service Oriented Architecture (SOA) approach that allows the reuse of both business logic and software components, thereby enabling service composition