Cyberphysical Human Systems

AN INTRODUCTION TO THE SPECIAL ISSUE

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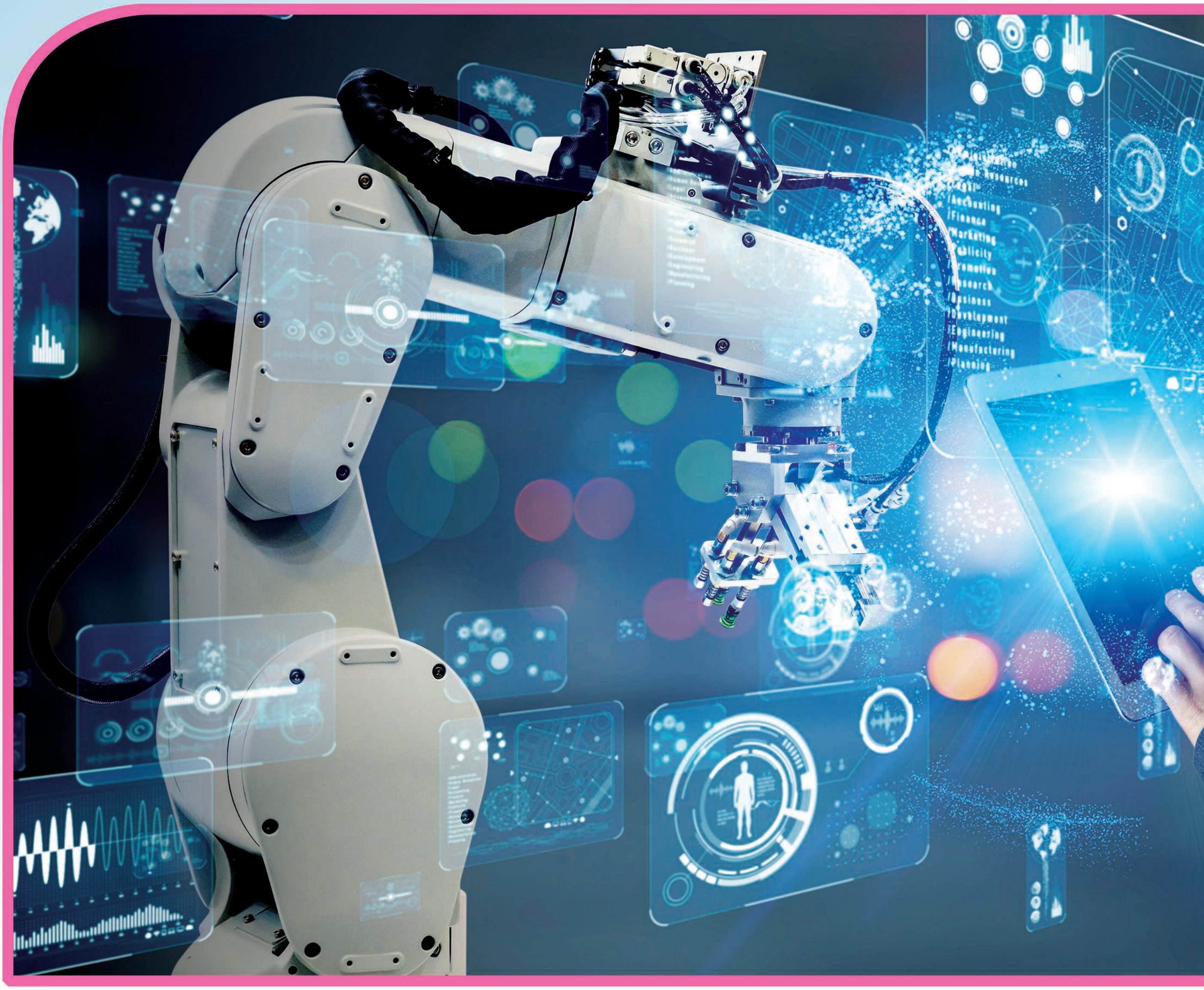

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Systems where humans, physical plants, and cybertechnologies are interconnected to accomplish a goal are called cyberphysical human systems (CPHSs). In CPHSs, humans are considered integral parts of complex cyberphysical systems (CPSs) that integrate communication, computation, control, and networking technologies into the underlying physical system. This contrasts with conventional wisdom, where humans are considered independent entities that are passive and consume, use, or operate these systems.

The field of CPSs was founded on the substantial progress made in control, communications, automation, and computing [1]. Recent research results are pushing the boundaries even further by studying ways to incorporate key cognitive functions such as perception, attention, and memory into the CPS framework [2] by drawing on ideas from cognitive neuroscience. As CPSs become more prevalent and as societal challenges multiply, the demand for humans to form stronger connections with CPSs increases. The interplay between the CPS and the human element is diverse, intricate, and challenging, requiring a careful, methodical analysis that forms the underpinnings of CPHSs [3].

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The importance and potential of automation design processes that acknowledge humans as integrated parts of the overall system (rather than as isolated entities) is being recognized by academia, industry, and government. According to a NASA report [4], for example, it is expected that automation systems that are inadequate in terms of properly addressing human–technology interactions will become riskier in the near future as mission requirements become more demanding and missions are conducted in unfamiliar environments. The risks include negative impacts to task times, workloads, and operators as well as increased cost and decreased performance. In the same report, a "good design" is defined as one where human integration into the system is well planned, among other things.

Similarly, in a U.S. Department of Defense report [5], it is stated that the taxonomy used to define the *levels of autonomy* creates a focus on machines, which, in turn, leads to designs that provide specific functions instead of providing overall resilient capability. The report suggests an alternative design for autonomous systems where *human–system collaboration* is prioritized. In [6], where a thorough analysis of the current and future roles of the system dynamics and control field is provided, the problem of "optimally conjugating automated systems with the interplay of humans" is presented as one of the grand challenges. These examples (and many others not expressed here) openly manifest an emerging recognition of the value created by studying the human element and the related CPS as a single system, namely, a CPHS. The aim of this special issue is to present an overview of some of the recent research in CPHSs.

RESEARCH CHALLENGES

There are several important questions that must be addressed to achieve high-performance, reliable, and low-cost CPHSs that benefit humanity. Some of these questions are listed below.

- How would the health, safety, and welfare of humans be guarded as CPHSs become more complex, capable, and widespread in society (see [7] for a detailed discussion)?
- How does one build a CPHS such that the operation of the system is not hindered by the misuse of automation due to too much or too little human trust?

As CPSs become more prevalent and as societal challenges multiply, the demand for humans to form stronger connections with CPSs increases.

- How do we estimate and employ a human's intent such that the resulting CPHS performs within certain safety boundaries?
- How can the limits of human behavior (such as bias, cognitive fatigue, and computational constraints) be predicted, modeled, and used in CPHS design?
- How do we share responsibility between the automation and human decision making in CPHSs?
- How do we develop the appropriate sensors, tools, and algorithms to measure/estimate human body movements and emotions? How can one process and use this information to establish automation systems for (as an example) medical rehabilitation?

ARTICLES IN THE SPECIAL ISSUE

There are five articles in this special issue addressing different aspects of CPHS challenges:

- "Human-in-the-Loop Robot Control for Human–Robot Collaboration," by Dani et al., addresses the challenges of estimating human intent in collaborative tasks to achieve safe trajectory tracking of robots.
- "Behavioral Economics for Human-in-the-Loop Control Systems Design," by Protte et al., investigates the effects of human behavioral imperfections on the performance of CPHSs.
- "Shared Control Between Pilots and Autopilots," by Eraslan et al., proposes solutions for the problem of responsibility sharing between humans and automation in the aerospace domain.
- "Human Trust-Based Feedback Control," by Akash et al., presents a method to alleviate the consequences of disuse or misuse of automation when the human's trust is not properly managed.
- "Inertial-Sensor-Controlled Functional Electrical Stimulation for Swimming in Paraplegics," by Wiesener et al., presents the results of a recent experimental study on the closed-loop control of human joint angles and torques for improving quality of life.

AUTHOR INFORMATION

Yildiray Yildiz is an assistant professor and director of the Systems Laboratory at Bilkent University, Ankara, Turkey. He received the B.S. degree (valedictorian) in mechanical engineering from the Middle East Technical University, Ankara, Turkey, in 2002; the M.S. degree in mechatronics engineering from Sabanci University, Istanbul, in 2004; and the Ph.D. degree in mechanical engineering (with a mathematics minor) from the Massachusetts Institute of Technology, Cambridge, in 2009. He held postdoctoral associate and associate scientist positions with NASA Ames Research Center, Mountain View, California, from 2009 to 2010 and from 2010 to 2014, respectively. During this time, he was employed by the University of California, Santa Cruz, through its University Affiliated Research Center. He is the recipient of the American Society of Mechanical Engineers Best Student Paper in Conference Award (2008); the NASA Group Achievement Award (2012) for outstanding technology development; the Turkish Science Academy's Young Scientist Award (2017); the Science Academy, Turkey's Young Scientist Award (2017); and Prof. Mustafa N. Parlar Foundation's Research Incentive Award (2018). He has been an associate editor for the IEEE Conference Editorial Board since 2015, *IEEE Control Systems Magazine* since 2016, and *European Journal of Control* since 2019. He has also been a member of the *International Journal of Control* Editorial Board since 2019. He is currently a member of the IEEE CSS Board of Governors for the 2020 term. His research interests are the theory and applications of system dynamics and control. He is especially interested in human–machine interactions, adaptive control, reinforcement learning and game theory, and applications in the aerospace and automotive domains.

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