Networked Cyber-Physical Systems: An Introduction

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1 Introduction

The synergies of the cyberworld of the physical world are manifest in *cyber-physical systems (CPS)* (Fig. 1): the interconnection of sensors, actuators, and controllers enables us to monitor and affect local and remote physical environments. Cyber-physical systems have bearing on mobile sensors research in that mobility can be achieved through the distributed control of actuation devices, such as robots or unmanned autonomous vehicles. In this position paper, we give a brief introduction to our on-going research on networked CPS and its applications to mobile systems.

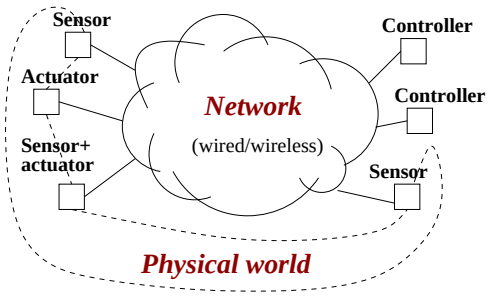

Figure 1: The *networked control* vision.

2 A Mobile CPS Example: Unmanned Ground Vehicles

An unmanned ground vehicle navigates and drives autonomously without local or remote human drivers. DARPA has launched the Urban Challenge, in which unmanned ground vehicles will maneuver in a mock city environment that includes roads, parking lots, busy intersections, obstacles, and moving traffic. TeamCase is the response of Case Western Reserve University to the DARPA Urban Challenge. TeamCase has fielded an autonomous vehicle called Dexter (Figure 2). Dexter hosts several sensors, such as cameras, radars, and lidars, and a distributed control system for sensor fusion and interpretation, competent decision making in ambiguous situations, the formulation of

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appropriate behaviors while interacting with other vehicles and robots, and automated planning and dynamic replanning.

Figure 2: TeamCASE unmanned ground vehicle: Dexter.

3 CPS Play-Back

CPS research spans multiple fields and themes. A complete review exceeds the scope of this white paper and can be found at `http://varma.ece.cmu.edu/cps/`. An example of CPS research is our own work on CPS play-back. Since the effectiveness of networked CPS depends on its ability to tolerate network non-determinism, we have investigated the use of play-back buffers to smooth out communication vagaries. Although play-back has been intensively studied in multimedia applications, play-back schemes differ significantly in CPS, which is characterized by different performance metrics and a different sequence of communication events. The primary contribution of our work is an end-to-end algorithm that integrates play-back buffers, sensor sampling, and control. The algorithm is extensively validated on simulations and real-time wide-area emulations. The integrated algorithm canceled the effect of disturbances as much as a proportional controller under ideal network conditions.

In general, CPS research is deeply multi-disciplinary and includes areas such as Computer Networks, Theoretical Computer Science, Programming Languages, and Control Theory, as well as the knowledge of application domains. In general, the CPS researcher needs to understand and talk to experts in a variety of areas of science and engineering. The multidisciplinary approach carries over to education, where Computer Science should become a new foundation stone for all undergraduate scientists and engineers.

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