Abstraction of Cyber-Physical Interplays and Its Application to CPS Design

Submitted by kgshin@eecs.umich... on Sun, 10/07/2012 - 9:27pm. Contributor:
Kang Shin

Abstract

Traditional ad hoc methods for the design of cyber-physical systems are increasingly insufficient in the face of complexities inherent to emerging systems. A key problem is the lack of suitable abstractions by which the controlled plant or process can be expressed in a form that is useful for decision-making across real-time task scheduling and control actuation domains. In this project, we are developing such abstractions and applying them to manage computer resources in a way that is properly responsive to the changing needs of the controlled plant.
Computer response time is central to our abstraction approach. Response time manifests itself to the controlled process as an important component of the feedback delay. Feedback delay has long been understood to significantly degrade the quality of control provided. By quantifying the degradation of control as a function of the response time, we are able to tie the responsiveness of the computer to the performance of the controlled process. This allows us to express the cost of incremental computer response time delays in terms that are physically meaningful to the controlled process (e.g., fuel consumption, time taken, etc.). Such cost functions can then be used to manage the resources of the computer. An efficient and lightweight heuristic has been obtained for scheduling tasks on the basis of these cost functions. A detailed case study of the steering and torque inputs to the wheels of an automobile has been undertaken. The effectiveness of scheduling on the basis of cost functions has been demonstrated for this application.
Similarly, physical plant regulation can be made responsive to computational process state. We are representing process state in terms of the execution of certain milestones in the code and the average rate (or frequency) at which the code is executing. Based on this computation state, the system may decide to alter its control strategies to better meet its objectives. For plant regulation, control gains can be adjusted to balance stability with expected performance, given physical and processor state and dynamics. Motion and computation rates can also be balanced, ensuring, for example, that the path planning time horizon always exceeds the current time by an appropriate margin.
We have devised complementary computational resource management techniques to regulate processor configuration, speeds/voltages, and task schedules using these abstractions. Our work allows an effective translation of the changing demands of the controlled process into computer- relevant terms and thereby increases the efficiency of processor resource management and failure recovery mechanisms.
We have also shown how to link the state of the controlled plant to the amount of fault- tolerance used by the controller. Life-critical systems have always used extensive levels of hard- ware (and often software) redundancy. The conventional approach is to maintain such levels of redundant computation irrespective of the state of the controlled plant. By adapting the extent of fault-tolerance used to the current state of the plant, significant reductions in processor loading have been made possible. Such reductions lead to a lowered thermal stress on the processors, thereby extending their expected lifespan. Extensive work has also been done on dynamically managing thermal stress by allocating and reallocating computational workload as appropriate.

Award ID: 0931013

Other available formats:

Abstraction of Cyber-Physical Interplays and Its Application to CPS Design

CPS Domains Design Automation Tools Concurrency and Timing Real-time Systems Control Systems Engineering Real-Time Coordination Manufacturing CPS Technologies Education Foundations National CPS PI Meeting 2012 2012 Poster Academia 0931035 0930813 CPS PI MTG 12 Posters & Abstracts