Battery Supported Cyber-physical Systems: A Robustness Perspective

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Summary: We have established a novel analytical approach to quantify robustness of scheduling and battery management for battery supported cyber-physical systems (CPSb). A dynamic schedulability test is introduced to determine whether tasks are schedulable within a finite time window. The test is used to measure robustness of a real-time scheduling algorithm by evaluating the strength of computing time perturbations that break schedulability at runtime. Robustness of battery management is quantified analytically by an adaptive threshold on the state of charge. The adaptive threshold significantly reduces the false alarm rate for battery management algorithms to decide when a battery needs to be replaced.

Approach: We follow an analytical approach to develop mathematical tools to measure robustness of real-time scheduling algorithms and battery management algorithms for CPSb during runtime. The mathematical tools produce exact solutions in terms of mathematical formulas to describe the interactions between embedded computers and batteries, which are complementary to results obtained using simulation or experimental methods.

Contributions: We have developed unified mathematical models for real-time scheduling in embedded computers that form the cyber components of CPSb, and for the discharging of batteries that form the physical components of CPSb. These mathematical models are also integrated with feedback controllers. By combining these mathematical models, we are able to study the interactions between the cyber and physical components analytically, this is well aligned with the main theme of CPS research. Several novel results have been generated by this analytical approach:

—Our robustness analysis incorporates both real-time scheduling and battery management algorithms. The robustness measures are able to account for situations at runtime that are unexpected at the designing stage.

—The dynamic schedulability test is an exact schedulability test for non-periodic task sets. We have also generalized the notion of robustness from periodic task sets to non-periodic task sets.

—Compared to existing battery management algorithms that use fixed thresholds for output voltage or for SoC to determine when to replace a used battery, our adaptive battery switching algorithm effectively reduces the false alarm rate.

Publications:

[1] F. Zhang, Z. Shi, and S. Mukhopadhyay "Robustness Analysis of Battery Supported Cyber-Physical Systems," *ACM Transactions on Embedded Computing Systems*, Submitted on October 8th, 2010, Second Revision on July 5th, 2011.

[2] F. Zhang, K. Szwaykowska, V. Mooney, and W. Wolf, "Task Scheduling for Control Oriented Requirements for Cyber-Physical Systems," in *Proc. of IEEE Real-Time Systems Symposium (RTSS 2008)*, 47-56, 2008.