Center for Embedded and Cyber-physical Systems
University of California, Irvine
University of California, Riverside

EXPLORATION OF THE CYBER-PHYISCAL DESIGN SPACE

Project: Design Science for Cyber Physical Systems (DesignSciCPS)

The Project

- Development of a Design methodology for Cyber-Physical Systems (CPS)

= a sequence of necessary and sufficient models, design decisions, and tools that systematically lead from a specification to the design of the final product.

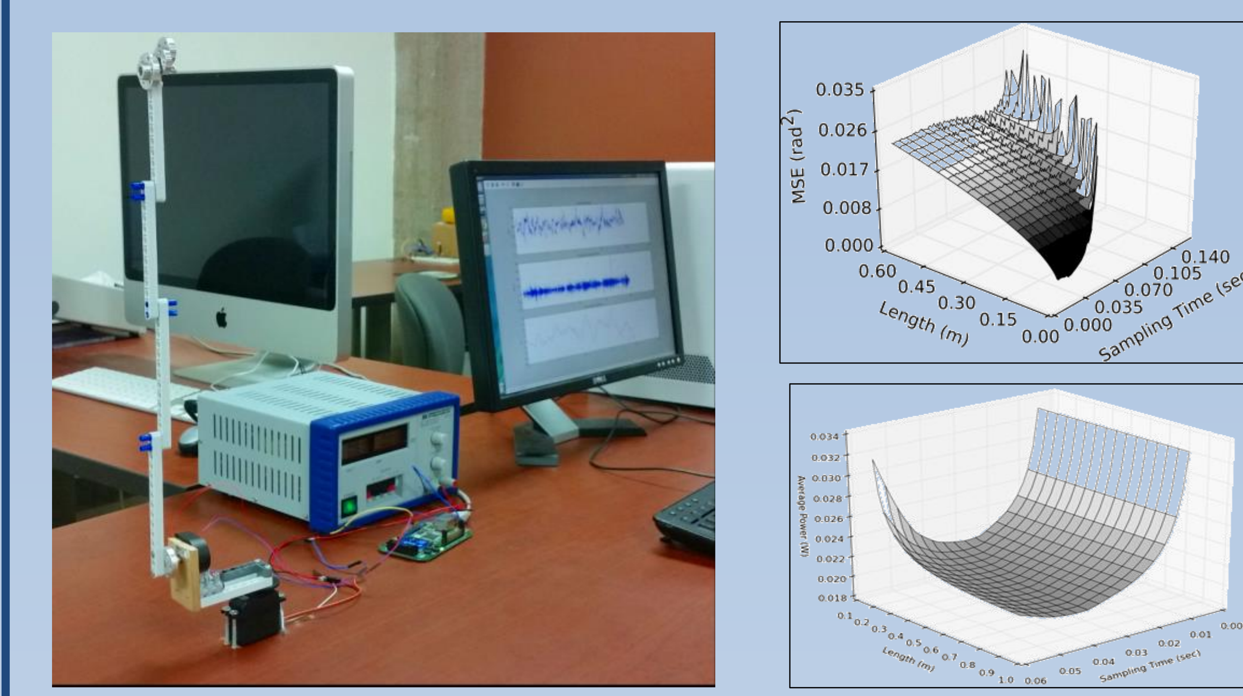
Goals

- Identification of superior Cyber-physical system designs
- Automatic exploration, taking into account domain-specific knowledge

Research Topics

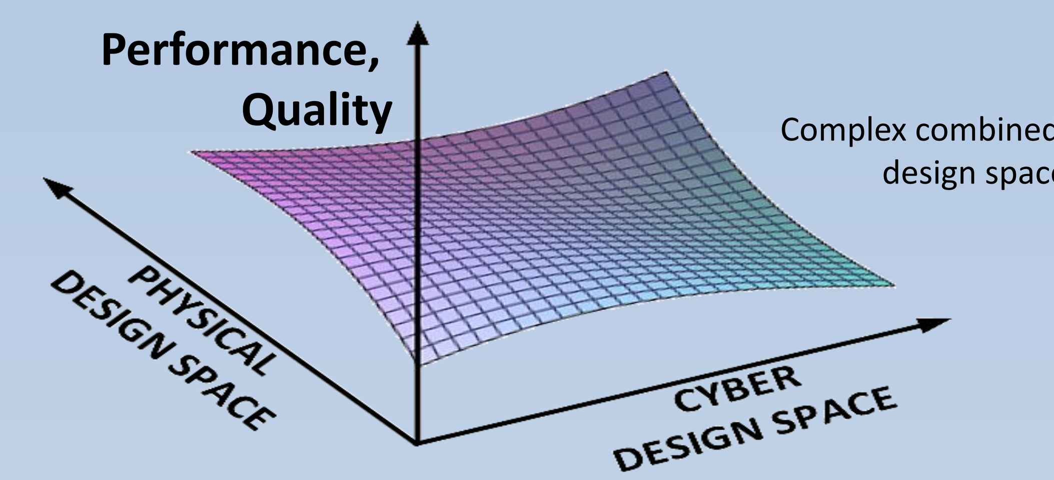
- Modeling of Physical System and Control
- Modeling of the Cyber System (Scheduling, Composability)
- Modeling and coping with uncertainties (faults, model s)
- Exploration strategies (Satisfiability, Tool support)

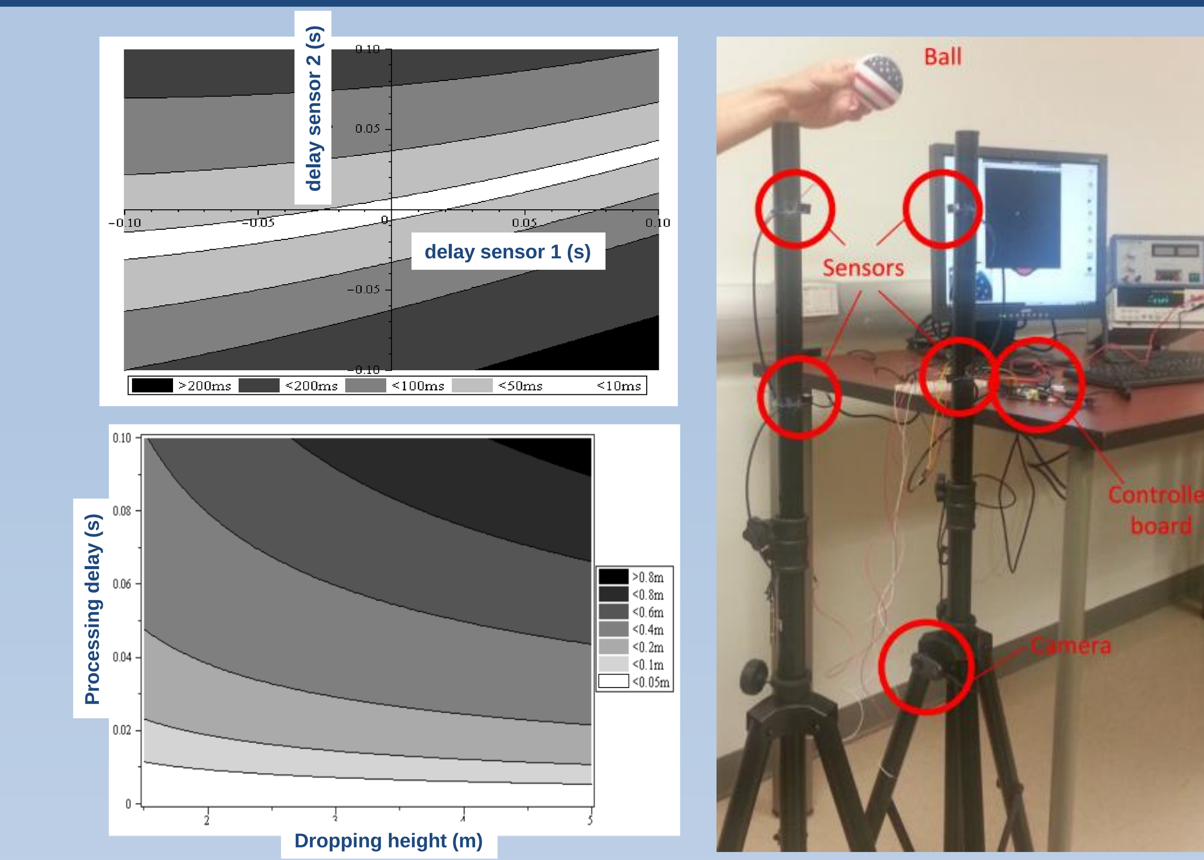
Cyber-physical design space



Rotary Inverted Pendulum: Control Quality (top) and Power consumption (bottom) are determined by length (physical) and sampling rate (cyber)

- Quality of a CPS design depends on a complex, multi-dimensional, multi-disciplinary design space
  - Physical design space (e.g. size, strength, pressure, voltage),
  - Cyber design space (e.g. frequency, architecture, platform)

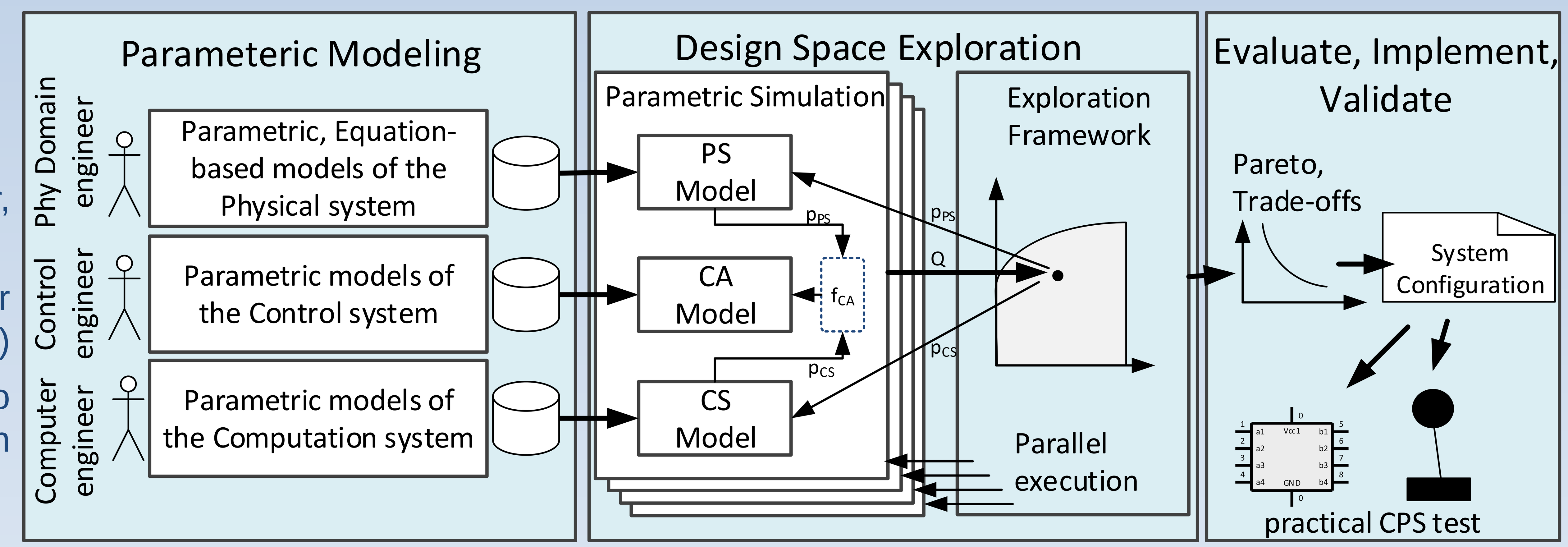




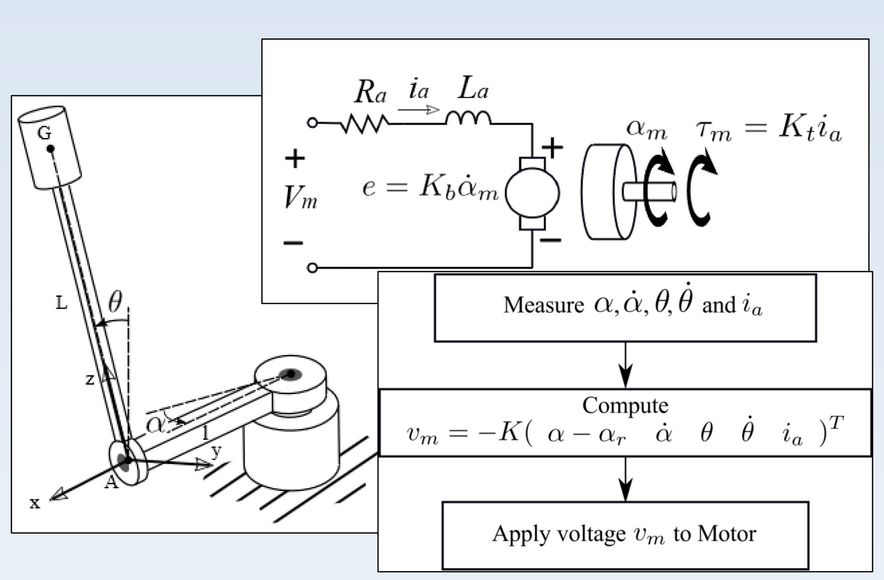
Falling Ball Example: System error as function of different sensor delays (top), required sensor position for different processing times and dropping heights (bot).

Exploration

- Holistic CPS design space exploration instead of sequential separation of concerns
- Apply parametric models of physical, cyber, and control, designed by domain experts
- Update control algorithm in context of cyber and physical systems (control-space-pruning)
- Automatic co-simulation and evaluation to assess properties and obtain superior design points to be implemented

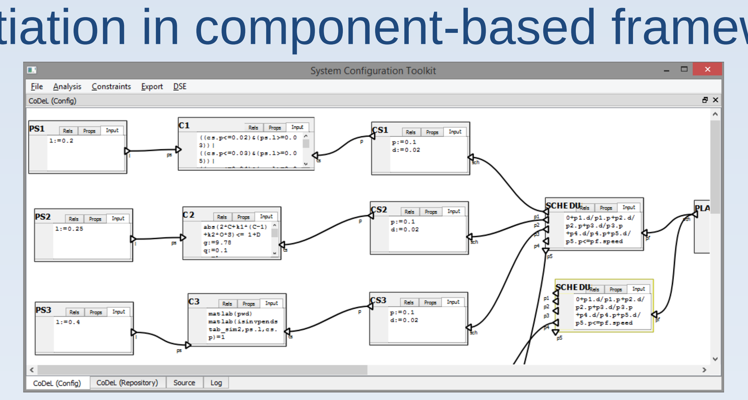


Use Case



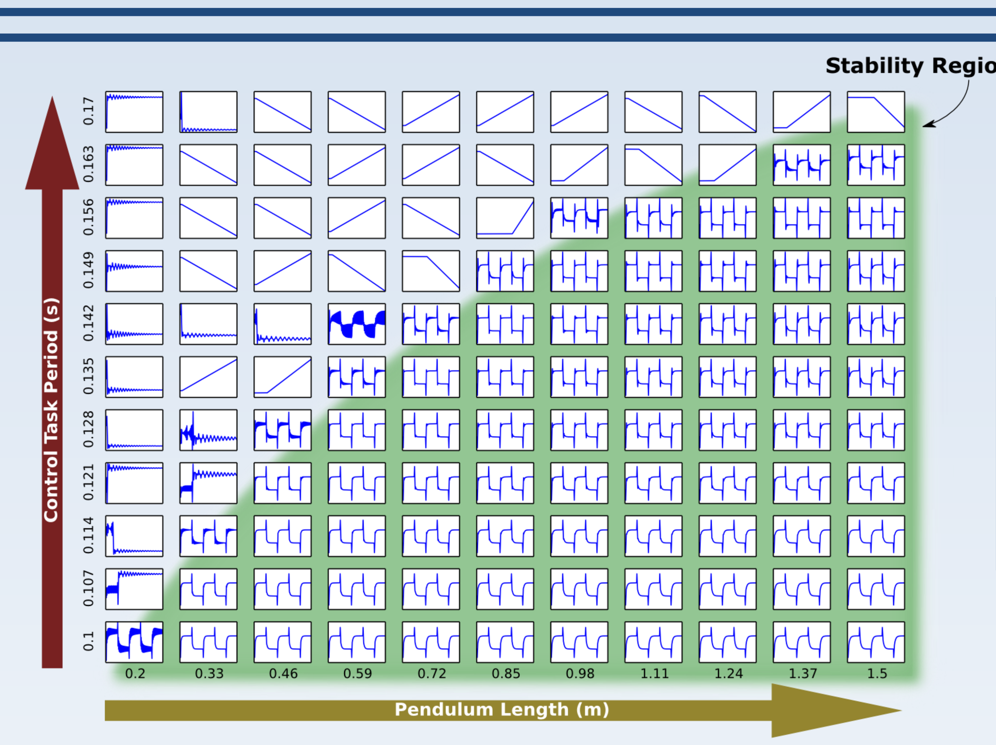
Parametric models of pendulum, DC motor, LQR control, and cyber system with fixed sampling rate

Instantiation in component-based framework

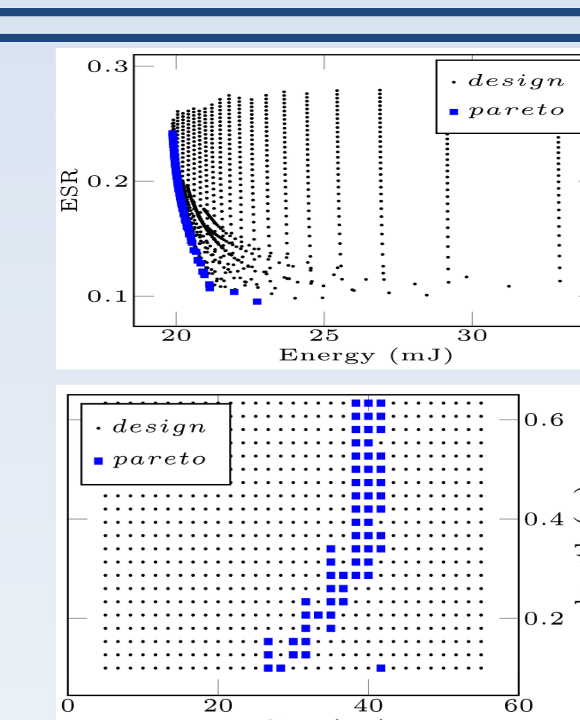


Run	Pruned	Size	Time
Simulink, interpreted		10^7	259 days (est)
Simulink, interpreted	+	10^4	7177 sec
Modelica, compiled		10^7	162 days (est)
Modelica, compiled	+	10^4	4471 sec
Modelica, parallel		10^4	87 sec

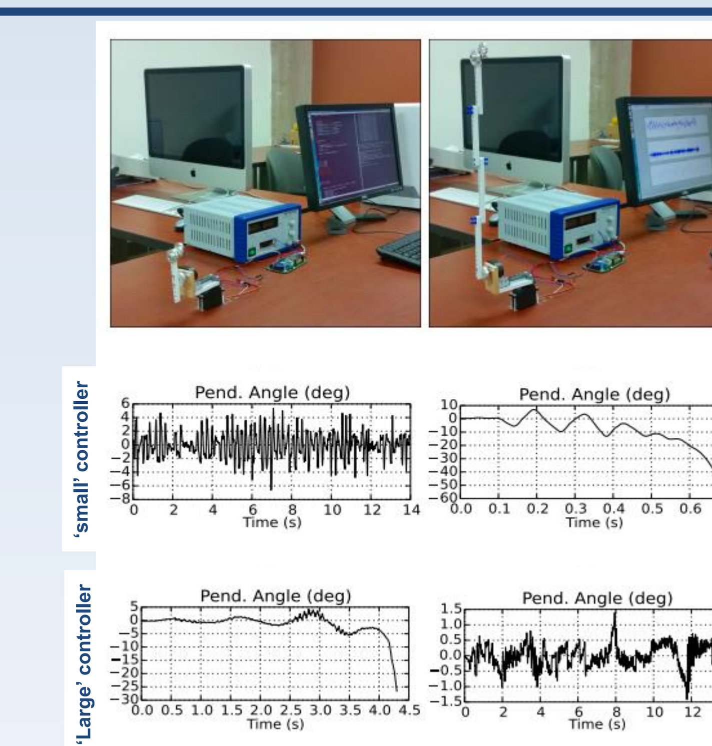
Systematic exploration with OpenModelica precompiled simulations on a 48 core Opteron server takes less than 90 seconds



Stability region for cyber-physical design space after controller pruning



Result: Control-to-energy consumption trade-off Pareto curve. Highlighted in blue are superior design points.



Practical validation: small vs. large pendulum design

Principle Investigators: Tony Givargis (givargis@uci.edu)
Daniel Gajski (gajski@uci.edu), Frank Vahid (vahid@cs.ucr.edu)

Web: **cps.ics.uci.edu**

Supported by the National Science Foundation under NSF Grant 1136146