CPS-Ed 2014

Cyber-Physical Systems Education Workshop at UC Berkeley

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Agenda

- Cyber-Physical Systems – Mechatronics
- Integrated Tool Suite

What's In A Name?

- Cyber-Physical Systems vs. Mechatronics
- "Mechatronics" not mentioned in this workshop description
- But, CPS curriculum at KTH is presented as:
  - "Mechatronics and embedded systems education at KTH"
- EE/CS vs. ME?
- Two curricula or one?

Mechatronics

- "Mechatronics" has been around since 1970s
  - Trademarked by Yasakawa then released
- Many books, journals
- Most programs (at least in US) have grown from (or within) ME departments
- Name is not as descriptive as it should be!
  - My focus is on "complex decision making"

Cyber-Physical Systems

- "CPS is an exciting new area attacking challenges at the interface where physical systems evolving in Newtonian time meet computational systems and networks evolving in cyber time" Raja Sengupta (he will speak later today)

CPS …

- "Cyber-Physical Systems (CPS) denotes the emerging class of physical systems that exhibit complex patterns of behavior due to highly capable embedded software components. Also known as hybrid systems (a hybrid of hardware and software), or mechatronic systems (mechanical + electronic), these include devices with content, or knowledge, that gives them unprecedented capabilities in interoperability and interaction, resilience, adaptivity, and emergent behavior."
- (http://www.nasa.gov/centers/ames/cct/office/studies/cyber-physical_systems_prt.htm)

CPS …

- Mechatronic Objects, Cyber-physical Systems, … Smart, networked Systems as a game-changer: New ways of cooperation among distributed and intelligent units. Interaction with human in a hybrid reality.
- (http://www.ias.uni-stuttgart.de/forschung/vortraege/weyrich/2014-05-27_Kol-Techn-Kyb-.pdf)

Unity?

- More similarities than differences!
- Two names imply competition/differentiation rather than cooperation
- What's the core focus:
  - Primary value-added is in software
- Not resolving this is likely to lead to a "hard" focus (mechanical systems) in ME based programs and a "soft" focus (computation) in EE/CS based programs

Are Specialists Needed at BS Level?

- Most of us would probably say yes
- It hasn't happened in U.S.
  - Only 3 ABET BS programs in mechatronics
  - Vaughn College, Southern Polytechnic State University, California State University, Chico
- Many more outside of U.S.
  - 6 ABET BS mechatronics programs outside U.S.!
  - There seem to be about 60 in Europe

Integrated Tool Suite Project

- Motivation:
  - Mechanical CAD, simulation, and embedded control are each well developed
  - However, they are not well integrated
  - Simulation, in particular, is often left out because it is “less essential,” that is, the project can proceed without it

Two Steps Instead of Three!

- There are two main creative steps in most mechatronic/cyber-physical systems:
  - Design, manufacture of the physical system
  - Design, implementation of the control system
- Present practice requires a third creative step, design and implementation of the simulation if one is to be used
- This step can be made much more mechanical

Industry + Academia

- James Truchard, CEO/President of National Instruments, Carl Bass, CEO/President of Autodesk, and Shankar Sastry, Dean of UC Berkeley College of Engineering
- Together they have proposed a program to develop an Integrated Tool Suite
- This project is just starting

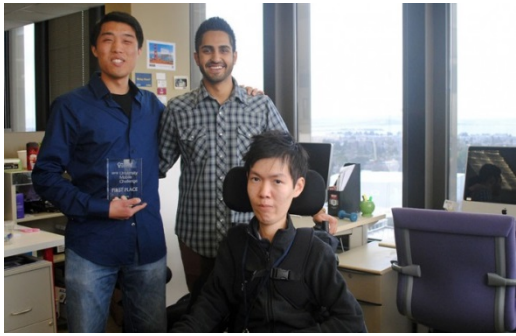
Jacobs Institute for Design Innovation

- One inspiration for the Integrated Tool Suite program is our new design-focused Institute
- Undergraduate emphasis; multi-disciplinary
- Test bed for tool suite
- Some slides from Dean Sastry on CPS and design…

Design Innovation: Fostering New Ideas & Building Teams

SkyDeck, Cal's startup accelerator, is home to Flowbit and Dreambox, two new Berkeley technology ventures.

The UC Berkeley "**Flowbit**" team takes 1st place in international competition with mobile water monitoring design. March 2013.



Berkeley Engineering student entrepreneurs design the first fully automated 3D printing vending machine, called "**Dreambox**." Customers can select an object or enter their own design and watch it print before their eyes, on campus. March 2013.

Cal team makes finals of Disney Design national challenge. Their project: Sustainable Automated Meal Mobile (**SAMM**). January 2013.

Digital Design and Manufacturing Tools

Mechanical Design

- Incorporating structures, materials, fracture
- Rapid prototyping
- Small volume manufacturing
- Sustainable Manufacturing
- Exemplar Tools: AutoCAD, Pro-Engineer, …

Embedded Intelligence

- Incorporating CPS design principles: correctness by construction, fault tolerance, etc.
- Security and Resilience: the ability to work through attacks
- Exemplar Tools: NI Lab View, NI Matrix X, Matlab, etc.

- **Technology Challenges to develop Instructional Digital Design and Manufacturing Tool Suites**

- **Heterogeneous Abstractions, Modularity and Composability**
- **Physics Based Models allowing for co-design, co-simulation and co-verification**
- **Agility in Production, for example in high precision manufacturing**
- **Resilience (Security) engineering**

Integrated Tool Suite: What We're Hoping To Do

- Notice that slide listing tools (2 back) has only two columns but the next slide highlights "Physics Based Models"
- Our goal is to fill the "middle" column
- Modern CAD is "parametric"
  - Object-oriented in computational terms
  - Contains enough information to generate physics-based simulations

Simulation: Powerful Productivity Tool But Under Utilized

- Enables parallel development of hardware and control software
  - Control software is often tested and debugged only against real hardware
- Behaviors elicited during simulation testing can be fed back to the hardware development process
- It is very important to minimize the change in control software going from simulation to real

Why Aren't Simulations Used More?

- *Ad Hoc* simulations are too expensive, too time consuming, and require resident experts
- As a result, simulations tend to be used only where they ARE essential, *i.e.*, the system is:
  - Too dangerous (nuclear power plant)
  - Too slow (Building thermal behavior would be a good example but performance spec is weak!)
  - Inaccessible (space vehicles)
  - Too expensive

The Integration Piece

- Use data from CAD to auto-generate a simulation that can accommodate control code compatible with the embedded environment that will be used in the actual product

Challenges

- Open source environment connecting two proprietary environments (initially Inventor from AutoDesk and LabView/Embedded from National Instruments)
  - Will require active participation from NI and AutoDesk
- Including multiple media (CAD describes mechanical but system may include electronics, hydraulics, etc.)

Challenges …

- Suitable math/numeric/computational environment to host simulations
  - Physics-based simulations so need to track power/energy
  - Differential-algebraic (DAE) capability
  - ODE and/or PDE as needed
- Fitting in with undergraduate engineering curriculum
  - The curriculum does not have much room for the kind of intensive activity this will need

Conclusions/Discussion

- Cyber-Physical Systems and Mechatronics must be unified to make best use of scarce academic resources and to clearly define industrial needs
- The integrated tool suite has the potential to fill a critical gap. Making the concept-to-production process smoother will make both education and industry more efficient