technische universität dortmund

fakultät für informatik
informatik 12

(Introduction to)
Embedded Systems

Peter Marwedel
TU Dortmund,
Informatik 12

Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

Slides selected/adjusted for EECS 222C by R. Doemer (based on V2010/09/20)

Motivation for Course (1)

According to forecasts, future of IT characterized by terms such as

- Disappearing computer,
- Ubiquitous computing,
- Pervasive computing,
- Ambient intelligence,
- Post-PC era,
- Cyber-physical systems.

Basic technologies:

- *Embedded Systems*
- Communication technologies

Embedded Systems & Cyber-Physical Systems

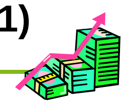
<u>“Dortmund“ Definition:</u> [Peter Marwedel]

Embedded systems are information processing systems embedded into a larger product

<u>Berkeley:</u> [Edward A. Lee]*:*
Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.

☞ **Definition**: **Cyber-Physical (cy-phy) Systems** (CPS) are integrations of computation with physical processes [Edward Lee, 2006].

Growing importance of embedded systems (1)



- *the global mobile entertainment industry is now worth some $32 bln…predicting average revenue growth of 28% for 2010* [www.itfacts.biz, July 8th, 2009]
- *…, the market for remote home health monitoring is expected to generate $225 mln revenue in 2011, up from less than $70 mln in 2006, according to Parks Associates. .* [www.itfacts.biz, Sep. 4th, 2007]
- *According to IDC the identity and access management (IAM) market in Australia and New Zealand (ANZ) … is expected to increase at a compound annual growth rate (CAGR) of 13.1% to reach $189.3 mln by 2012* [www.itfacts.biz, July 26th, 2008].
- Accessing the Internet via a mobile device up by 82% in the US, by 49% in Europe, from May 2007 to May 2008 [www.itfacts.biz, July 29th, 2008]

Growing importance of embedded systems (2)

- .. *but embedded chips form the backbone of the electronics driven world in which we live ... they are part of almost everything that runs on electricity*
  [Ryan, EEDesign, 1995]
- Creation of the ARTEMIS Joint Undertaking in Europe
- Funding of CPS research in the US
- Foundation for the "post PC era"
- ES hardly discussed in other CS courses
- ES important for TU Dortmund
- ES important for Europe
- Scope: sets context for specialized courses

Importance of education (applies to: Foundation for the "post PC era" through Scope: sets context for specialized courses)

Application areas and examples

Automotive electronics

Functions by embedded processing:

- ABS: Anti-lock braking systems
- ESP: Electronic stability control
- Airbags
- Efficient automatic gearboxes
- Theft prevention with smart keys
- Blind-angle alert systems
- ... etc ...

Multiple networks

- Body, engine, telematics, media, safety, ...

Multiple networked processors

- Up to 100

© Jakob Engblom

Avionics

- Flight control systems,
- anti-collision systems,
- pilot information systems,
- power supply system,
- flap control system,
- entertainment system,
- …

Dependability is of outmost importance.

Railways

- Safety features contribute significantly to the total value of trains, and dependability is extremely important

Telecommunication

- Mobile phones have been one of the fastest growing markets in the recent years,
- Geo-positioning systems,
- Fast Internet connections,
- Closed systems for police, ambulances, rescue staff.

Medical systems

- For example:
  - Artificial eye: several approaches, e.g.:
    - Camera attached to glasses; computer worn at belt; output directly connected to the brain, “pioneering work by William Dobelle”. Previously at [www.dobelle.com]

- Translation into sound; claiming much better resolution. [http://www.seeingwithsound.com/etumble.htm]

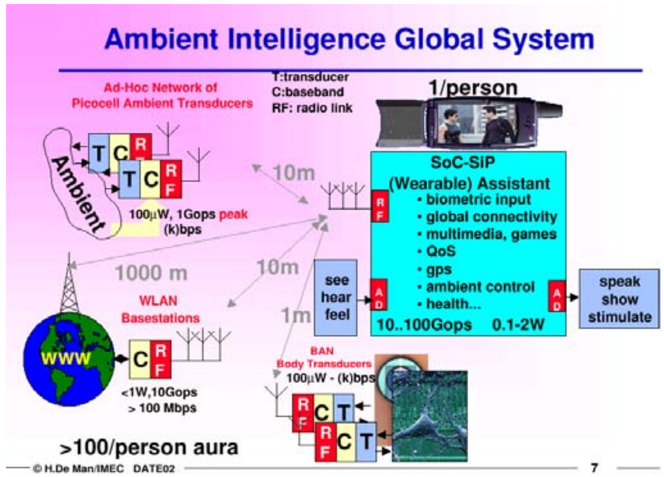
Authentication systems

- Finger print sensors
- Access control
- Airport security systems
- Smartpen®
- Smart cards
- ….

[tomsguide.com]

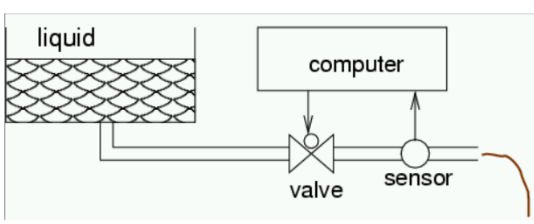
Consumer electronics

Examples

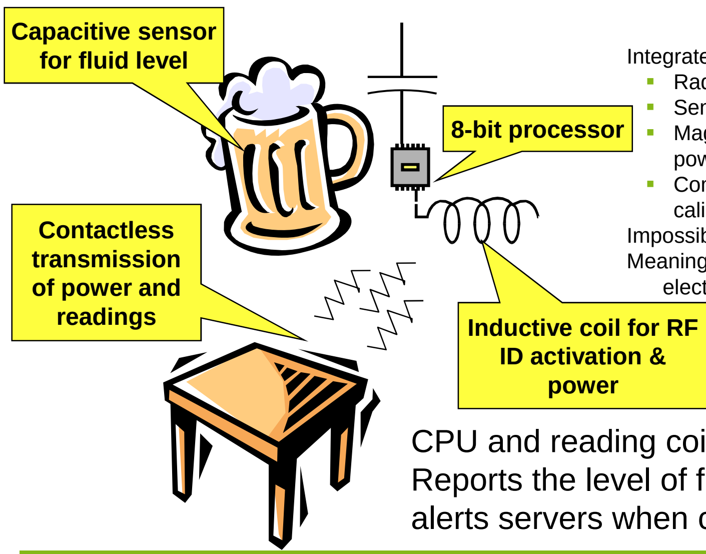


Industrial automation

Examples



Smart Beer Glass



Integrates several technologies:
- Radio transmissions
- Sensor technology
- Magnetic inductance for power
- Computer used for calibration

Impossible without the computer
Meaningless without the electronics

CPU and reading coil in the table. Reports the level of fluid in the glass, alerts servers when close to empty

Forestry Machines

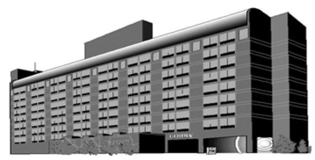
Networked computer system
- Controlling arms & tools
- Navigating the forest
- Recording the trees harvested
- Crucial to efficient work

“Tough enough to be out in the woods”

Smart buildings

Examples

- Integrated cooling, lightning, room reservation, emergency handling, communication
- Goal: "Zero-energy building"
- Expected contribution to fight against global warming



Show movie http://www.date-conference.com/conference/2003/keynotes/index.htm

Logistics

Applications of embedded/cyber-physical system

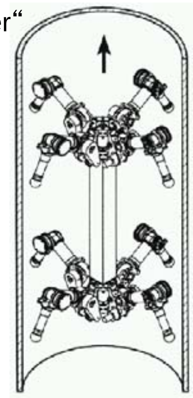
technology to logistics:

- Radio frequency identification (RFID) technology provides easy identification of each and every object, worldwide.
- Mobile communication allows unprecedented interaction.
- The need of meeting real-time constraints and scheduling are linking embedded systems and logistics.
- The same is true of energy minimization issues

Robotics

Examples

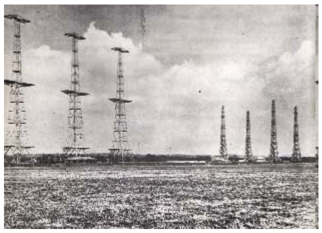
- "Pipe-climber"



- Robot "Johnnie" (Courtesy and ©: H.Ulbrich, F. Pfeiffer, TU München)

Military applications

Example:
- Military radar

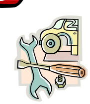


http://www.worthingherald.co.uk/CustomPages/CustomPage.aspx?SectionID=14271 technische universität dortmund

fakultät für informatik informatik 12

Common characteristics

Dependability

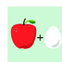
- ES Must be **dependable**, 
  - **Reliability *R(t)* =** probability of system working correctly provided that it was working at *t*=0 
  - **Maintainability *M(d)* =** probability of system working correctly *d* time units after error occurred. 
  - **Availability *A*(*t*)**: probability of system working at time *t*
  - **Safety**: no harm to be caused 
  - **Security**: confidential and authentic communication 

Even perfectly designed systems can fail if the assumptions about the workload and possible errors turn out to be wrong.

Making the system dependable must not be an after-thought, it must be considered from the very beginning

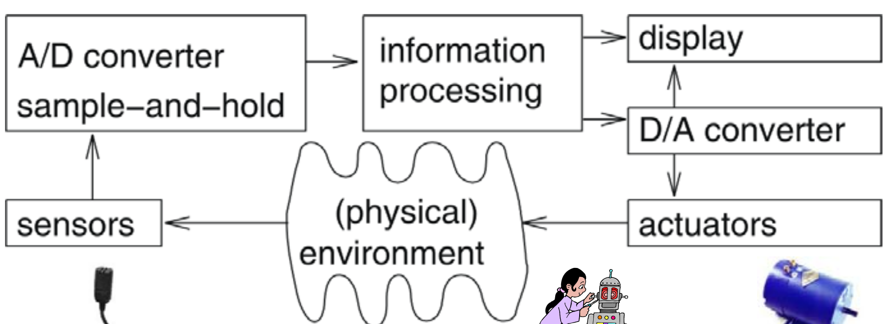
Efficiency

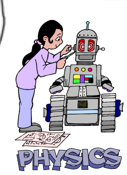
- ES must be **efficient**
  - Code-size efficient (especially for systems on a chip)
  - Run-time efficient
  - Weight efficient
  - Cost efficient
  - Energy efficient



Embedded System Hardware

Embedded system hardware is frequently used in a loop (***"hardware in a loop"***):





☞ cyber-physical systems

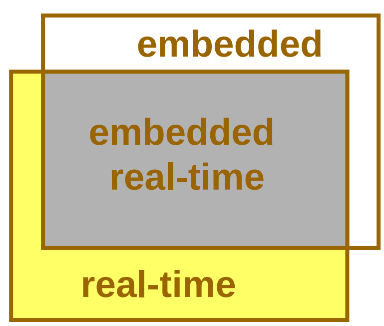
Real-time constraints

- Many ES must meet **real-time constraints**
  - A real-time system must react to stimuli from the controlled object (or the operator) within the time interval **dictated** by the environment.
  - For real-time systems, right answers arriving too late are wrong.
  - **"A real-time constraint is called hard, if not meeting that constraint could result in a catastrophe"** [Kopetz, 1997].
  - All other time-constraints are called **soft**.
  - A guaranteed system response has to be explained without statistical arguments

Real-Time Systems

Embedded and Real-Time Synonymous?

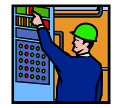
- Most embedded systems are real-time
- Most real-time systems are embedded



© Jakob Engblom

Reactive & hybrid systems

- Typically, ES are **reactive systems**:
  "A reactive system is one which is in continual interaction with is environment and executes at a pace determined by that environment" [Bergé, 1995]
  Behavior depends on input **and current state**.
  ☞ automata model appropriate,
  model of computable functions inappropriate.



- **Hybrid systems**
  (analog + digital parts).

Dedicated systems

- **Dedicated** towards a certain **application**
  Knowledge about behavior at design time can be used to minimize resources and to maximize robustness
- **Dedicated user interface**
  (no mouse, keyboard and screen)

Underrepresented in teaching

- ES are **underrepresented in teaching** and public discussions:
  "*Embedded chips aren't hyped in TV and magazine ads ...*" [Mary Ryan, EEDesign, 1995]

Not every ES has all of the above characteristics.

Def.: **Information processing systems having most of the above characteristics are called embedded systems.**

Course on embedded systems makes sense because of the number of common characteristics.

Summary

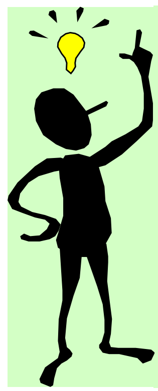
- A look at the future of IT
- Definition: embedded & cyber-physical (cy-phy) systems
- Growing importance of embedded & cy-phy systems
- Application areas
- Examples
- Characteristics

- Plus: The Importance of Embedded Software (from 2006/07 set of slides)

Importance of Embedded Software and Embedded Processors

"... the New York Times has estimated that the average American comes into contact with about 60 micro-processors every day...." [Camposano, 1996]

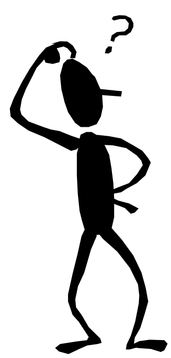
Latest top-level BMWs contain over 100 micro-processors [Personal communication]



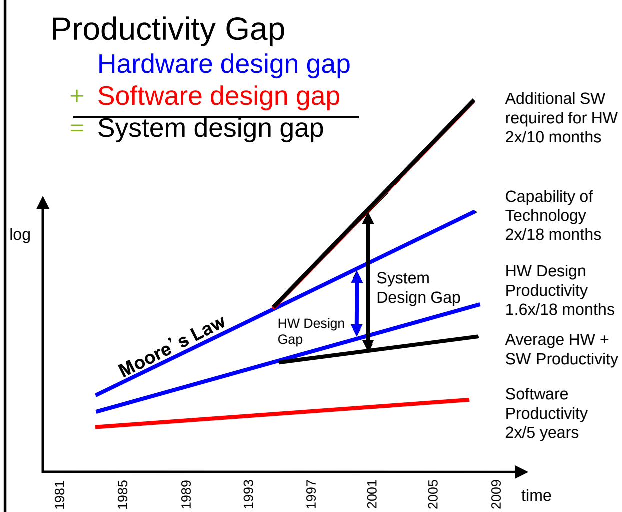
Most of the functionality will be implemented in software

Challenges for implementation in software

If embedded systems will be implemented mostly in software, then why don't we just use what software engineers have come up with?



Software Complexity if a Challenge



(source: *"Hardware-dependent Software"*, Ecker et al., 2009)

- Exponential increase in software complexity
- In some areas code size is doubling every 9 months [ST Microelectronics, Medea Workshop, Fall 2003]
- *... > 70% of the development cost for complex systems such as automotive electronics and communication systems are due to software development* [A. Sangiovanni-Vincentelli, 1999]

Challenges for Embedded Software

- Dynamic environments
- Capture the required behaviour!
- Validate specifications
- Efficient translation of specifications into implementations!
- How can we check that we meet real-time constraints?
- How do we validate embedded real-time software? (large volumes of data, testing may be safety-critical)






Software complexity is a challenge

- Exponential increase in software complexity
- In some areas code size is doubling every 9 months [ST Microelectronics, Medea Workshop, Fall 2003]
- *... > 70% of the development cost for complex systems such as automotive electronics and communication systems are due to software development* [A. Sangiovanni-Vincentelli, 1999]

Rob van Ommering, COPA Tutorial, as cited by: Gerrit Müller: Opportunities and challenges in embedded systems, Eindhoven Embedded Systems Institute, 2004