UNIVERSITÄT DORTMUND

Embedded Systems

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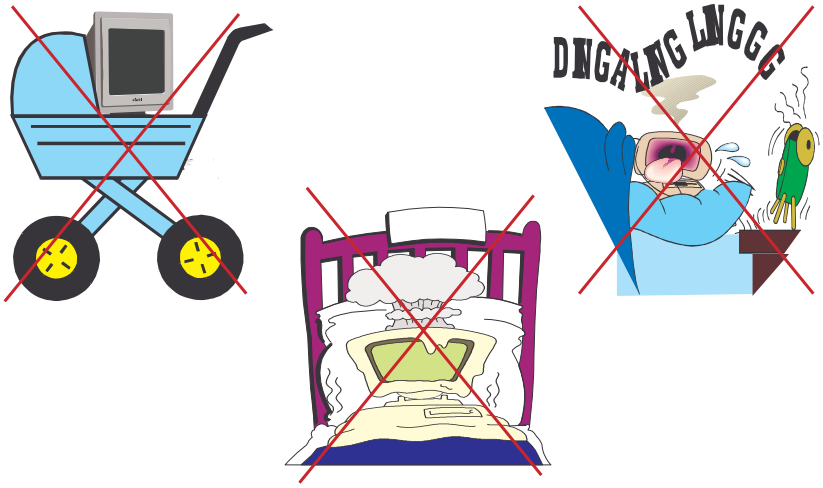
Future of IT?

According to forecasts characterized by the terms such as

- *Post-PC era*
- *Disappearing computer*
- *Ubiquitous computing*
- *Pervasive computing*
- *Ambient intelligence*
- *Embedded systems*

What is an embedded system?



Embedded Systems

Embedded systems (ES) = **information processing systems embedded into a larger product**

Main reason for buying is **not** information processing

Application areas (1)

- Automotive electronics
- Aircraft electronics
- Trains
- Telecommunication



Artificial Eye

Several approaches

– Camera attached to glasses; computer worn at belt; output directly connected to the brain, “pioneering work by William Dobelle”. Previously at [www.dobelle.com]

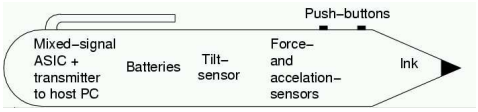

– Translation into sound; claiming much better resolution. [http://www.seeingwithsound.com/etumble.htm]

Application areas (3)

- Military applications

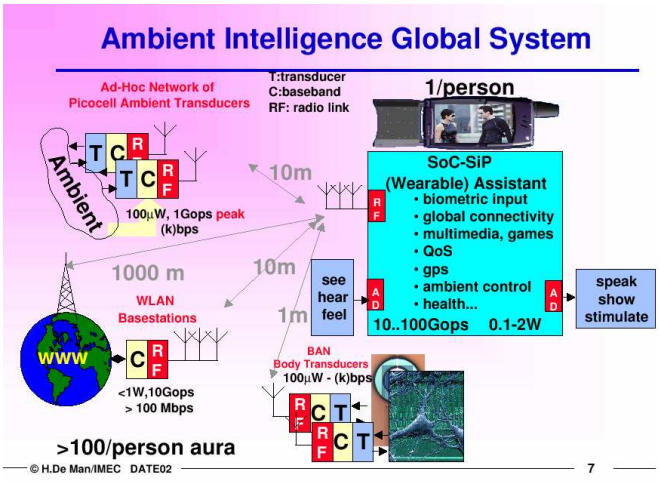
http://www.submarine.co.mp/wallpaper/submarine_640.jpg

- Authentication



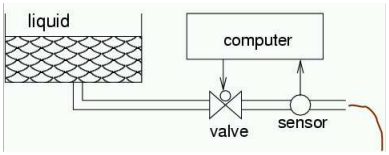
Application areas (4)

- Consumer electronics



Application areas (5)

- Fabrication equipment

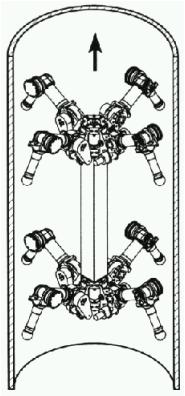


- Smart buildings

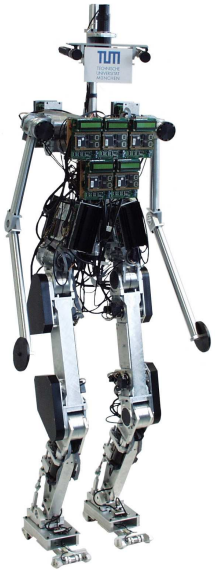
Application areas (6)

- Robotics

„Pipe-climber“



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



Examples

Some embedded systems from real life

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Information Technology

Pedometer

- Obvious computer work:
  - Count steps
  - Keep time
  - Averages
  - etc.
- Hard computer work:
  - Actually identify when a step is taken
  - Sensor feels motion of device, not of user feet

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Information Technology

Mobile phones

- Multiprocessor
  - 8-bit/32-bit for UI
  - DSP for signals
  - 32-bit in IR port
  - 32-bit in Bluetooth
- 8-100 MB of memory
- All custom chips
- Power consumption & battery life depends on software

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Information Technology

Mobile base station

- Massive signal processing
  - Several processing tasks per connected mobile phone
- Based on DSPs
  - Standard or custom
  - 100s of processors

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Information Technology

Telecom Switch

- Rack-based
  - Control cards
  - IO cards
  - DSP cards
  - ...
- Optical & copper connections
- Digital & analog signals

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Information Technology

Sewing Machine

- User interface
  - Embroidery patterns
  - Touch-screen control
- ”Smart”
  - Sets pressure of foot depending on task
  - Raise foot when stopped
- New functions added by upgrading the software

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Information Technology

Cars

- Multiple processors
  - Up to 100
  - Networked together
- Multiple networks
  - Body, engine, telematics, media, safety

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Information Technology

Cars

- 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 ...

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Information Technology

Cars

- Large diversity in processor types:
  - 8-bit – door locks, lights, etc.
  - 16-bit – most functions
  - 32-bit – engine control, airbags
- Form follows function
  - Processing where the action is
  - Sensors and actuators distributed all over the vehicle

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Information Technology

Extremely Large

- Functions requiring computers:
  - Radar
  - Weapons
  - Damage control
  - Navigation
  - basically everything
- Computers:
  - Large servers
  - 1000s of processors

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Information Technology

Inside your PC

- Custom processors
  - Graphics, sound
- 32-bit processors
  - IR, Bluetooth
  - Network, WLAN
  - Harddisk
  - RAID controllers
- 8-bit processors
  - USB
  - Keyboard, mouse

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Information Technology

If you want to play

- Lego mindstorms robotics kit
  - Standard controller
    - 8-bit processor
    - 64 kB of memory
  - Electronics to interface to motors and sensors
- Good way to learn embedded systems

Growing importance of embedded systems (1)

- Growing economical importance of embedded systems THE growing market according to forecasts, e.g.:
  - *Worldwide mobile phone sales surpassed 156.4 mln units in Q2 2004, a 35% increase from Q2 2003, according to Gartner* [www.itfacts.biz]
  - *The worldwide portable flash player market exploded in 2003 and is expected to grow from 12.5 mln units in 2003 to over 50 mln units in 2008* [www.itfacts.biz]
  - *Global 3G subscribers will grow from an estimated 45 mln at the end of 2004 to 85 mln in 2005, according to Wireless World Forum.* [www.itfacts.biz]

Growing importance of embedded systems (2)

- *The number of broadband lines worldwide increased by almost 55% to over 123 mln in the 12 months to the end of June 2004, according to Point-Topic.* [www.itfacts.biz]
- *Today's DVR (digital video recorders) users - 5% of households - will grow to 41% within five years, according to Forrester.* [www.itfacts.biz]
- *The automotive sector … ensures the employment of more than 4 million people in Europe. Altogether, some 8 million jobs in total depend on the fortunes of the transport industry and related sectors - representing around 7 per cent of the European Union's Gross National Product (GNP)* [OMI bulletin]

Growing importance of embedded systems (3)

- .. *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* [Mary Ryan, EEDesign, 1995]
- 79% of all high-end processors are used in embedded systems

The future is embedded, Embedded is the future!

- Foundation for the „post PC era“
- ES hardly discussed in other CS courses
- ES important for Technical University
- ES important for Europe
- Scope: sets context for specialized courses

Importance of education

Characteristics of Embedded Systems (1)

- Must be **dependable**,
  - **Reliability *R(t)* =** probability of system working correctly provided that is 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

Characteristics of Embedded Systems (2)

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

Characteristics of Embedded Systems (3)

- 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

Characteristics of Embedded Systems (4)

- Frequently **connected to physical environment** through sensors and actuators,
- **Hybrid systems** (analog + digital parts).

- 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.

Characteristics of Embedded Systems (5)

- 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.

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]

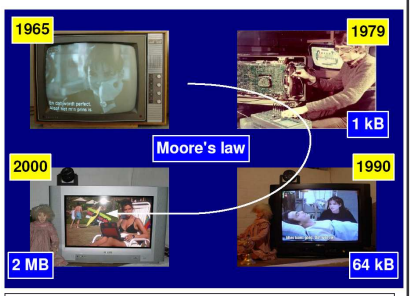
Most of the functionality will be implemented in software

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 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

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)