Portable Telemedical Monitoring Using Wireless Sensors on the Edge of the Internet

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Intelligent monitors

- Sudden collapse victims, result of
  - circulatory
  - hypoxemic
  - traumatic arrest
- estimated mortality 350,000 lives/year
- economic cost of trauma related injuries $400 billion / year (NIH PA-01-054)

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Intelligent Personal Monitors

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Can we make it without wires?

- Wireless infrastructure
  - 700 million subscriber units by 2002
- Mobile computing
  - system on chip
- Intelligent wireless sensors
- Intelligent health monitors / warning devices
- Personal Area Network (PAN)
  - body network / intelligent clothes
  - wireless personal area network
  - hierarchical processing

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Solution?

Wireless Personal Area Network of Intelligent Sensors

+

Hierarchical Digital Signal Processing

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Problems of existing systems?

- Development environment
  - custom VLSI, assembler?
- Resources for sophisticated real-time processing
  - memory
  - speed
- Price

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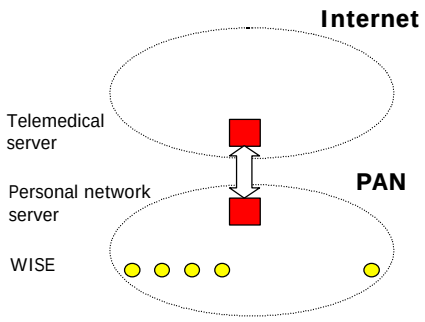
Wireless Personal Area Network

- Wireless network of intelligent sensors
- Wireless Intelligent Sensor (WISE)
- Piconetwork
- Sensors
  - EEG
  - ECG
  - breathing
  - movement



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Wireless Intelligent Sensor WISE

- Low power microcontroller TI430F149
  - 16-bit RISC architecture, 60KB flash, 2KB RAM
  - ultra-low power consumption (400 µA in active mode, as low as 0.8 µA in standby mode)
  - 8 channels (12+2 bit A/D)
- Wireless transceiver
  - LINX RF transceiver 916MHz
  - 33.6 Kbps data transfer rate
  - adjustable power/range
- Biomedical amplifier
  - Teledyne TETMD A110 (ECG/EEG amplifier)
  - custom amplifiers

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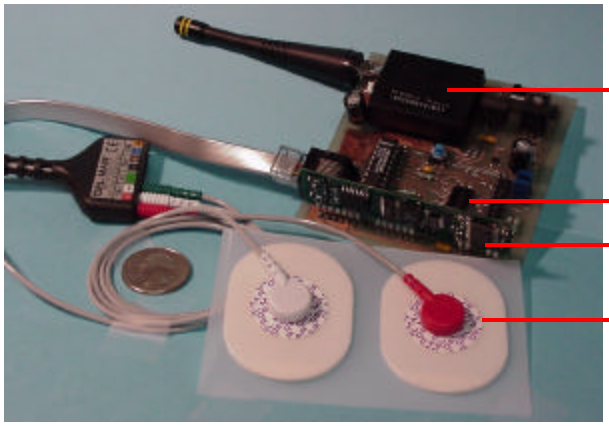
WISE Architecture



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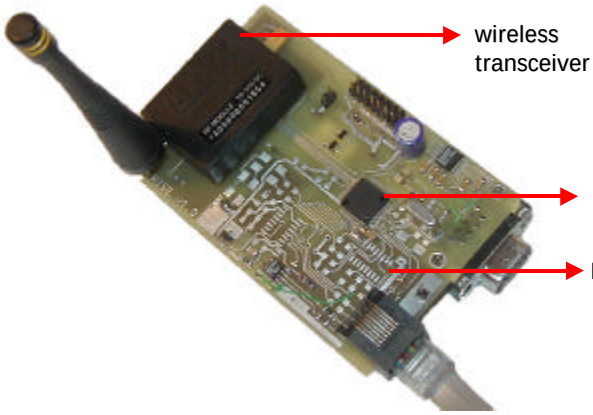
WISE Ver. 1.2



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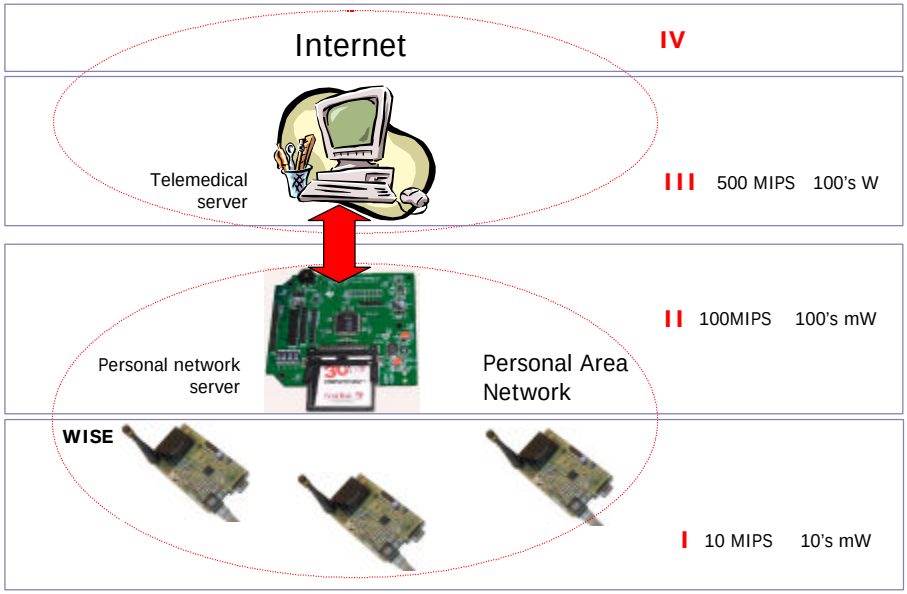
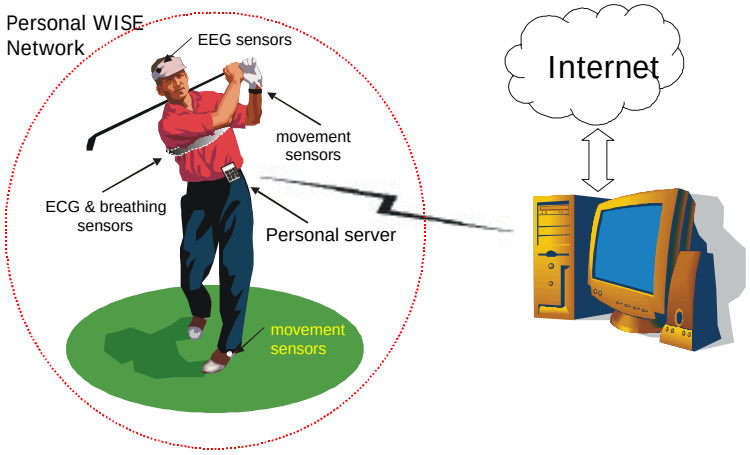
Hierarchical Signal Processing



Wireless PAN configuration



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Hierarchical DSP System Design

- Constraint programming
  - set of constraints
- Process scheduling
- Performance evaluation
- Energy profiling
- Iterative process

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Process scheduling issues

- System parameters
  - execution time
  - energy per process
  - communication
- Constraint based scheduling

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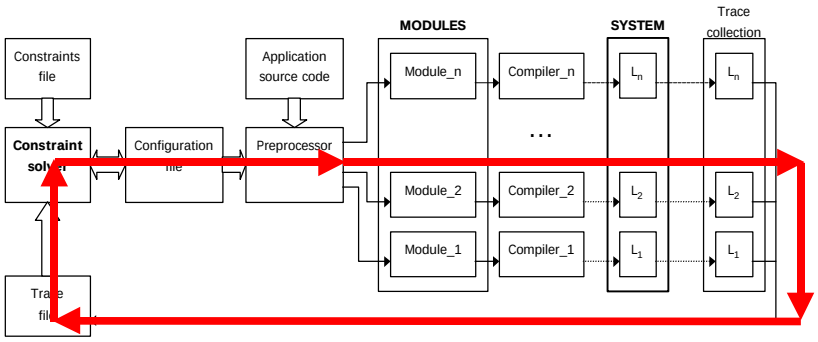
System Implementation



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Hierarchical process scheduling

I Workstation

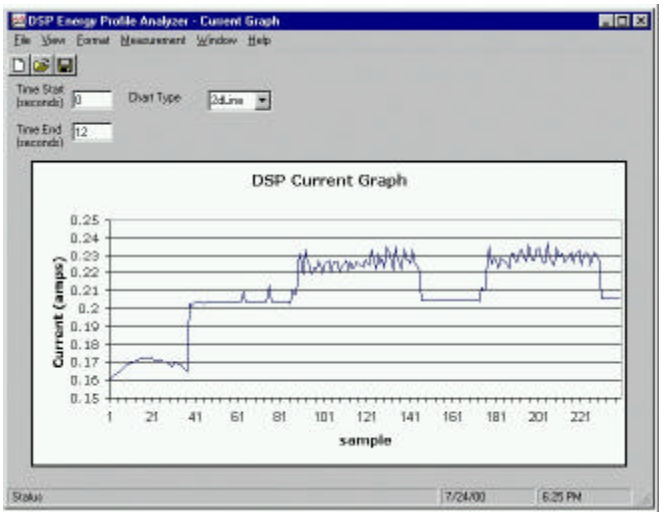
II DSP

III μC

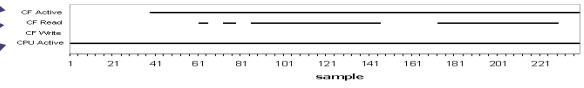
Environment for dynamic energy profiling

Jovanov, et al., "Environment for Energy Profiling of DSP Applications", ICSPAT 2000, Dallas, TX.

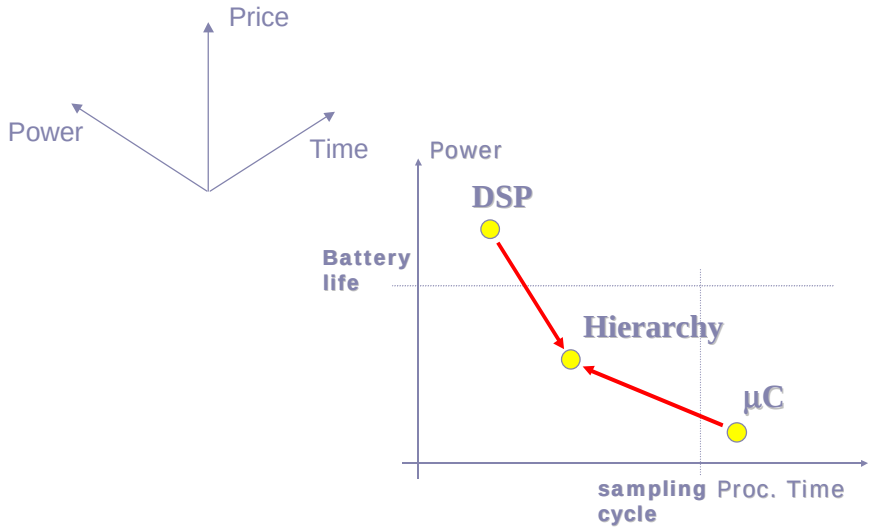
DSP Application Profiling Example



CF Active
CF Read
CPU Active



Exploring the design space



Examples

- ECG analysis (ischemic event monitor)
- Activity monitor
- Breathing monitor
- Civil Disaster Data Acquisition Device

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ECG Analysis

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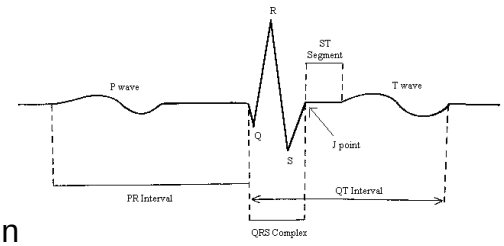
ECG analysis



- Sophisticated analysis in
  - High performance/low power DSP
- Warnings (sometimes life saving)
- Typical ECG processing algorithms
  - Initialization (thresholds, polarity, gain control)
  - Filtering (band pass filters, notch filters)
  - QRS complex detection
  - Heart rate variability processing
  - Baseline correction
- Robust algorithms

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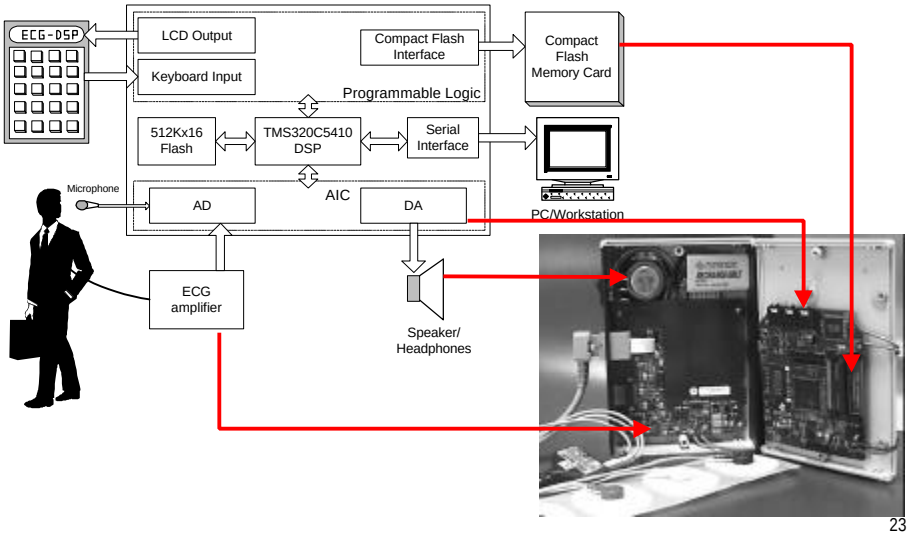
ECG Holter Development Environment



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Hierarchical processing issues

- Data mining on higher levels
- Adaptive thresholds
- Multi-sensor synergy
  - running/sitting?
- Environmental effects

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User activity monitoring

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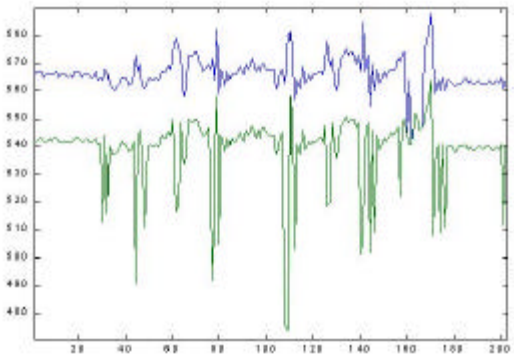
Accelerometer based Wireless Intelligent Sensor

- Analog Devices ADXL 202/210 MEMS
- Digital front-end of WISE



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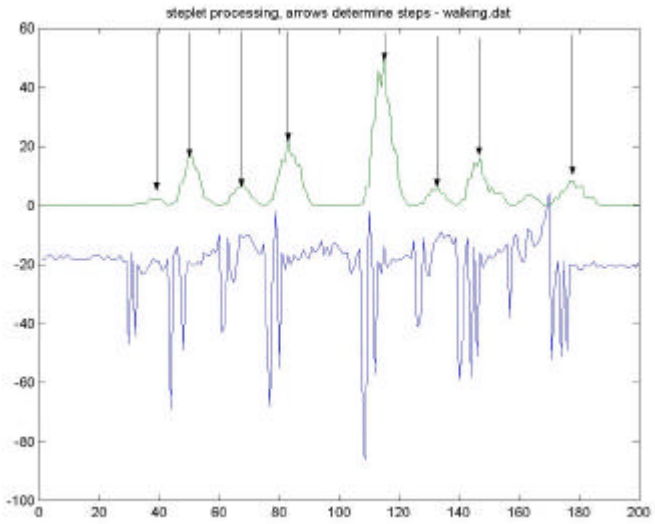
Alternative processing methods



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Breathing sensor

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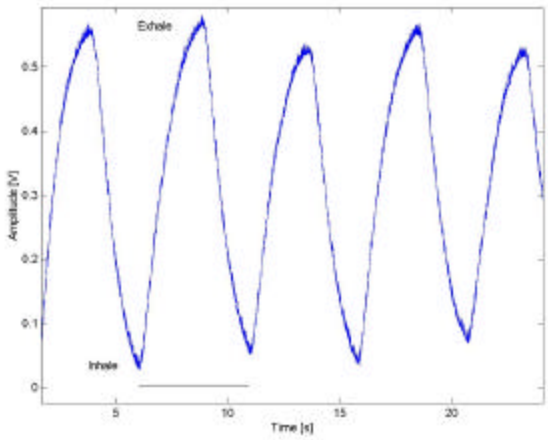
Breathing sensor

- Custom analog front end
- Thermistor based differential breathing sensor



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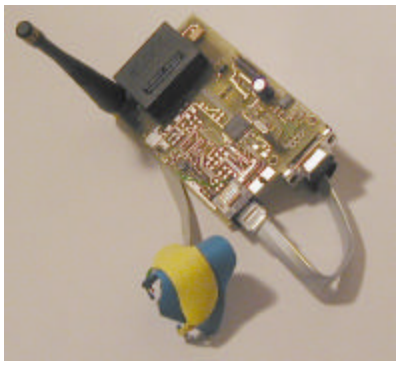
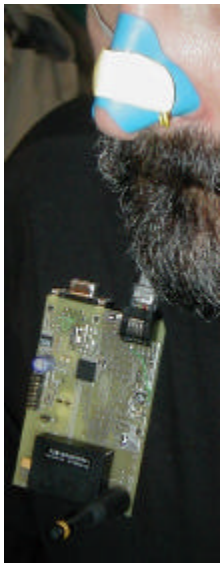
Circadian breathing rhythm analysis

- Wireless link
- When_available archiving
- Hierarchical processing





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ECG system setup and monitoring

- System setup & debugging
- Visual Basic application on portable computer
- WISE Gateway with serial link interface

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Wearable physiological monitors

- ECG (heart activity)
  - myocardial ischemia
  - arrythmia
  - circadian rhythm analysis of heart rate variability
- EEG (brain activity)
  - epileptic seizure detection
  - drowsiness detection
- Heterogenous sensors (polygraphy)
  - sleep apnea monitoring
  - physical therapy feedback for stroke victims
  - new generation human-computer interfaces

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Wireless PAN - Applications

- Wearable physiological monitors
  - intelligent monitoring/early warnings
  - decrease hospitalizations & nursing visits
- Intelligent control of medication
  - sensing, dosing and compliance monitoring
- Aids for disabled
- Computer assisted rehabilitation
  - stroke victims
  - supervised heart attack rehabilitation
- Battlefield soldier monitoring
- Advanced human-computer interfaces

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Conclusion

- Enabling technology for a new generation of telemedical systems and intelligent sensors
- Sensor technology
  - Implantable sensors as natural extension
    - glucose blood monitors, drug pumps
- Optimum drug administration
- Prolonged monitoring
- Portable “guardian angel”
- Research issues
  - resource allocation
  - constraint solving
  - power optimal system organization

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Acknowledgments

DSP Challenge

- Dejan Raskovic
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