Wireless Biomedical Sensing
Challenges and Opportunities

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Tampere, Finland
Content

• Institute of measurement and information technology (MIT), Sensor Technology group
• Wireless biomedical sensing
  – Requirements, technological challenges and possibilities, applications
• Short-range links
• Project examples (PROACT, TULE, WISEPLA)
• BIRCA Consortium
• ITALH – International cooperation project
• Conclusion
Measurement and Information Technology (MIT)

Research and teaching
– Research and educational activities of the institute are focused on the subjects of fundamental measurement science, sensor technology and measurement information technology
– Special emphasis is placed on developing practical and theoretical skills through experimental work and research projects

Staff
– 3 full-time professors: Jouko Halttunen (Head of the institute), Jukka Lekkala (Sensor Technology), and Risto Ritala (Measurement Information Technology)
– 2 teaching assistants, 1 laboratory engineer, 2 secretaries
– ~30 researchers and research assistants

MIT in numbers
– Total budget 1.587 M€ (2005)
– 11 MSc theses (2005)
Sensor Technology

Teaching and research
- Sensor physics and new sensing materials
- Modelling and simulation
- Focus in microsensors, biosensors and wireless sensors
- Applications of commercial sensors
- 6 researchers, 6 research assistants
Measurement and Information Technology

Clean room facility

- The clean room has a 22 m² floor area and the class 7 (10000 particles per cubic foot), in a laminar flow cabinet the class is around 1000
- The room is equipped with **photolithography system** including a photoresist spinner, hot plate, mask aligner and exposure device (Karl Süss MJB-3, 2 µm resolution), wet etching station, a water purification system, and a microscope
- The laboratory is intended for **microsensor and biosensor prototyping**
New wireless biomedical sensing systems

- New technology, e.g. ambulatory or implantable wireless sensors, will dramatically change the way we understand healthcare today.

- This development provides the enabling technology for real long term monitoring of physiological functions in sports, home healthcare as well as in hospital environment.

- The healthcare system will become more mobile, demand driven, efficient, and person/patient friendly.

- New wireless sensors and measurement systems have a huge market potential.
Human Sensing

Diagnostics
- Bioelectrical and physiological measurements (ECG, arrhythmia, other heart symptoms, EEG, EMG, blood pressure, ….)
- Biochemical assays (blood sugar, infarct markers, ….)

Safety
- Monitoring of chronically ill patients (heart diseases, diabetes, epileptic events), alarms
- Monitoring at home and in nursing homes (elderly and demented people)

Sport, physical exercise, training
- Monitoring of physical condition and efficiency
- Control and feedback in training

Ambient intelligence, smart devices, security
- Environment senses, recognizes and reacts (home, office, car)
- Smart user interfaces (telephone, PC, multimedia devices, digital-TV, games)
Physiological Measurements

Sensors…

Physical or chemical parameter, condition or its change

+ signal processing/data handling → measurement information
Biomedical Sensing – How?

Requirements for new measurement devices:

- Light weight and small size
- Flexible, soft, textile like material
- Biocompatible
- Easy to install and use → no wires, no connectors
- Possibly (partly) disposable → low priced
- Low power consumption → no or small batteries → energy harvesting
- Reliable and secure (data privacy)
Light wireless measurement systems - What is needed?

• Compact electrodes and sensors
  – New electrode materials
  – Silicon microsensors, nanosensors
  – *In vivo* biosensors and biochips
  – New sensing materials
  – New ideas for sensing
Electrode – skin interface

- **Wearable monitoring – Challenge: How to reduce motion artefacts?**
  - Flexible and elastic electrode materials
    - Textile and fabric electrodes
    - Flexible strips or plasters
  - Solid gels or adhesives
    - Hydrogels, conductive elastomers
    - Biocompatible bonding agents, “Compeed”-electrodes
  - Active electrodes (preamplifier integrated in the electrode)
  - Capacitive electrodes

→ Smart active MEMS-based electrodes?
What is needed?

- Miniature electronics
  - High degree of integration and packaging
    - 3D System-in-Package
  - Low power consumption, µ-Batteries
  - Wireless powering methods
    - Inductive, capacitive, ultrasonic, light
  - Energy harvesting
    - Vibrations; piezoelectric and smart materials
    - Temperature gradient; thermopiles
What is needed?

Wireless links

• Several short-range radios and protocols available:
  – Ultra Wide Band (UWB)
  – IEEE 802.11 WLANs
  – Bluetooth
  – ZigBee
  – ANT
  – TUTWS

• Inductive links

• IR-links
Frequencies – “Limited Natural Resource”

European Radiocommunications Committee (ERC)

RECOMMENDATION 70-03
RELATING TO THE USE
OF SHORT RANGE DEVICES
(SRD)

www.ero.dk/documentation/docs/doc98/official/pdf/REC7003E.PDF
(Version of 17 November 2005)

Frequencies for different applications are listed in the Annexes

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Table 1: Applications

ISM = Industrial Scientific Medical (ITU)
**Annex 12  Wireless applications in Healthcare**

**Scope of Annex**
This annex covers frequency bands and regulatory as well as informative parameters recommended for wireless applications in healthcare.

**Regulatory parameters related to Annex 12**

<table>
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<th>Frequency Band</th>
<th>Power</th>
<th>Duty cycle</th>
<th>Channel spacing</th>
<th>ECC/ERC Decision</th>
<th>Notes</th>
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<tr>
<td>a  402 - 405 MHz</td>
<td>25 µW e.r.p.</td>
<td>No Restriction</td>
<td>25 kHz</td>
<td>ERC/DEC/(01)17</td>
<td>The application is for ultra low power active medical implants (for convenient definitions see EC Directive 90/385/ECC) Individual transmitters may combine adjacent channels for increased bandwidth up to 300 kHz</td>
</tr>
<tr>
<td>b  9 - 315 kHz</td>
<td>30 dBµA/m at 10 m</td>
<td>&lt; 10 %</td>
<td>No spacing</td>
<td></td>
<td>The application is for ultra low power active medical implant systems using inductive loop techniques for telemetry purposes</td>
</tr>
<tr>
<td>c  315 - 600 kHz</td>
<td>-5 dBµA/m at 10 m</td>
<td>&lt; 10 %</td>
<td>No spacing</td>
<td></td>
<td>The application is intended for animal implantable devices</td>
</tr>
<tr>
<td>d  30 - 37.5 MHz</td>
<td>1 mW e.r.p.</td>
<td>&lt; 10 %</td>
<td>No spacing</td>
<td></td>
<td>The application is for Ultra Low Power medical membrane implants for blood pressure measurements</td>
</tr>
</tbody>
</table>
**Example**

Heart rate monitor
- Electric ECG signal is measured by using a band around chest
- The heart rate is sent wirelessly (inductive link) to a receiver on wrist or belt
RFID Techniques

- Passive (no battery) Radio Frequency IDentification tag
- Reader sends a magnetic RF field for the transponder → the energy captured by its antenna activates the transponder
- Transponder returns its ID code by modulating the antenna circuit impedance

- Inductive 13.56 MHz (Rafsec)
- Inductive 134.2 kHz and 13.56 MHz (Texas Instruments)
- Radio wave 868 MHz (Palomar)
VeriChip

The Food and Drug Administration (FDA) has approved an implantable microchip that can pass a patient’s medical details to doctors, speeding care

- VeriChips, radio frequency microchips the size of a grain of rice, have already been used to identify for example dogs and horses

- Chips have already been implanted in humans in Mexico and USA

- The chip’s serial number pulls up the patients' blood type and other medical information.

www.verichipcorp.com
RFID Sensors?

Radio Wave Reading (radiating system)

Source: Timo Varpula/VTT
Passive Wireless Sensors

A Wireless Batch Sealed Absolute Capacitive Pressure Sensor
Akar et al, EUROSENSORS XIV, The 14th European Conference on Solid-State Transducers August 27-30, 2000, Copenhagen, Denmark

Fig. 3: Equivalent circuit model of the telemetric readout approach.

6 µm silicon membrane
24 turns of gold-electroplated coil, inductance 1.2 µH
2.6 mm x 1.6 mm
Wireless Electrode System

Project “Wireless Technology and Psychophysiological Computing”

- PROACT (Pro-active Information Technology) Research Program of Academy of Finland
- Funding: 531 000 €, 2003 - 2005
- Co-operation partners: MIT and RGI institutes of TUT, and two research groups from University of Tampere (UTA)

The aim of the project was to develop wireless sensor technology that can be used for monitoring of behaviors that are related to human physiological and psycho-physiological responses during computer-user interaction.

www.cs.uta.fi/hci/wtpc/
Wearable measurement device

Wireless measurement cap

- Fabric electrodes for measuring EMG originating facial muscles, eye movements (EOG, gaze direction, blink) and EEG (electroencephalogram)
- 2 acceleration sensors
- EMFi thin film pressure sensor for heart rate measurement
- 6 wireless channels based on now-noise amplifiers and 2.4 GHz commercial Chipcon radio
- 1 kHz sample frequency/channel, 16 bits data
- Mobile phone battery
Examples of measured signals

- EMG (electromyogram) originating from facial muscles (behaviors related responses); corrugator and frontalis
- Accelerometers for sensing gesture of head (nodding and bending to the sides)
- Vertical and horizontal eye movements were recorded by measuring EOG (electro-oculogram). Also a signal from eye blinks are seen.

![EMG and Acceleration Signals](image1)

![EOG Signals](image2)
Wireless Implantable Sensors

- Project ”Wireless physiological sensors for ambulatory and implantable applications”
- Future Electronics Research Program of Academy of Finland
- Co-operation partners: MIT, RGI, ELE (Institute of Electronics) and BIOM (Institute of Biomaterials) from TUT

Wireless sensors will be developed and demonstrated in certain soft and hard tissue implant applications such as implantable electrodes for detection of ECG or bone implant monitoring.

www.ele.tut.fi/tule
Technology Concept

- Inductive wireless link (125 kHz, 13 MHz) data transfer and power delivery for the implant
- General implantable sensor platform + read-out electronics and signal and data processing
- Miniature size (inserted with a syringe?)
Wireless implantable sensor technology is the only way to realize reliable long term monitoring of physiological signals?
**Applications 1(2)**

**Implantable ECG monitor**

- where and how to make the measurement?
- to whom and why is the information sent?

Many possibilities:
- ECG signal, heart rate
- monitoring/alarm

Implant can also include:
- temperature sensor
- microphone for heart or breathing sounds
- acceleration sensor

*In vitro* prototypes during 2005

First animal *in vivo* tests with the implant prototype during June 2006
Several prototypes tested

Modeling:
- location and size of the implant
- expected signal amplitude

Testing of electrodes and biomaterial coatings (polymers, parylene, TiO$_2$, …)

Prototype with a coil antenna

On-skin testing result
Applications 2(2)

2. Implants and artificial organs

- Closing implant of thorax (after open heart surgery)
  - Measurement of closing force
  - Micro movements
- Smart hip prosthesis
  - Functionality feedback
  - Monitoring of loosening and wearing
- Sensing stent (support implant)
  - Opening during installation
  - Condition monitoring

• Short-range wireless sensor platform for ambulatory and implantable applications (FinnWell - Future Healthcare Technology Program of Tekes).

• The project will develop and provide wireless sensor platform technology utilizing new sophisticated 3D packaging of electronics and biocompatible encapsulation technologies.

• ECG/heart rate, impedance, different sensors

• Co-operation: MIT, RGI, ELE, BIOM Institutes of TUT and 11 participating companies

Test chip made by ELE/TUT
Other Applications

Pressure and flow sensors
- Blood pressure
- Cardiac Output (CO)

Biosensors
- Glucose
- Lactate
- Other analytes

Micro analyzers
- BioMEMS
- Microfluidics

CardioMEMS
www.cardiomems.com

Two ultra-miniature medical pressure sensors in the eye of a needle.
www.mems-issys.com
Integrated Glucose Monitoring System Concept

Sensors for Medicine and Science, Inc. (SMSI)

http://www.s4ms.com/products_glucose.htm
Integrated Glucose Monitoring System Concept

Fully Integrated “Grain” Design
BIRCA - Center and Alliance for Biosensing Research at TUT

- Physiological measurements and data analysis and modeling
- Sensors, sensor materials, Short-range wireless sensing
- Personal electronics, wireless systems
- Miniaturization of electronics, 3D packaging
- Biomaterials and in vitro testing

Most technology areas covered

RGI (Ragnar Granit Institute), Prof. Jari Hyttinen
ELE (Electronics), Prof. Jukka Vanhala
BIOM (Biomaterials) Prof. Minna Kellomäki
MIT (Measurement and Information Technology), Prof. Jukka Lekkala
ELE (Electronics), Dr. Pekka Heino
+ VTT, UTA, PIRAMK, TAMK
International Project Outline: INFORMATION TECHNOLOGY FOR ASSISTED LIVING AT HOME

- **Wireless systems**
  - Computer Vision
  - Data Analysis
  - Univ. of Berkeley
  - Mike Eklund
  - Sankar Sastry, CITRIS

- **Wearable, implantable and environment**
  - sensor systems, smart homes
  - Tampere Univ. of Tech

- **System Architecture and User Interfaces**
  - Smart spaces
  - Univ. of Aarhus
  - Morten Kyng

- **Common Experimental Prototypes and Local Test Sites**

**Cultural and organizational differences leveraged**

Partnerships with local and global companies of services and technology

Pilot projects for testing the developed wireless measurement systems and services
ITALH Projects in Finland

Finland 1M€/year

ITALH

Finland:
TUT
VTT

Denmark
Aarhus
Alexandra

Bay Area:
Berkeley,
CITRIS

Short-range wireless sensor platform for ambulatory and implantable applications
"WISEPLA"
Partners: TUT
Funding:
TEKES FinnWell 2006 -

Wearable Wellbeing project in Satakunta area
"PUHVI"
Partners: TUT
Funding:
TEKES/EAKR 2005 -

Light wireless "Smart home in a suitcase" home service support platform
"UUTE"
Partners: TUT, VTT
Funding: TEKES 2005 -

Projects directly under ITALH (coordinated by BIRCA)
Conclusion

• The present state-of-the-art technology enables development of completely new types of wireless devices for reliable long-term monitoring of physiological signals.
• The projects of Academy of Finland have created the basis for research of implantable medical devices in Finland.
• TUT, Tekes and several Finnish companies are participating in development of new advanced wearable wireless measurement systems.
• Multidisciplinary expertise and research teams are needed.
• Networking is important.
• New innovative products for health care and other applications.
Thank you!