Nano-Tera.ch

Engineering Complex Systems

for Health, Security and the Environment

Giovanni De Micheli
Emerging societal and economic issues

- Strengthening welfare
- Better, affordable health care and wellness
- Dealing with ageing and young population
- Mitigating risks
- Preventing catastrophes and pandemics
- Monitoring the environment
- Ensuring sustainability
- Smart energy production and distribution
- Intelligent water management
- Enhancing security
- Future of the internet
- Preventing cyber and physical attacks
The technology

Electronic and information technologies are keys to:

- Solving economic problems
- Supporting social dynamics

Public funding is important:

- Long term vision and objectives

Electronic systems go beyond chip design:

- Interfaces – including to the living world
- Actuation – including chemical delivery

Software plays a major role

System technology is build bottom-up, starting from materials and their properties

Nano-technologies will reshape products in various markets

Large scale networks will boost the value of new devices
Nano-Tera.ch

- **Health:**
  - High-throughput biology, real-time medical monitoring

- **Environmental monitoring:**
  - Weather, pollution, seismic analysis

- **Security:**
  - Cryptography, secure communication

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Mission

Research, Design & Engineering of complex tera-scale systems using nano-scale devices and technologies

Foster research and crossbreeding of hw/sw technologies

Convergence of technologies: fertile ground for innovation

- Develop new markets
- Improve living standards
- Better the quality of health, security & environment systems
- Foster a vision of engineering with social objectives
- Promote related educational programs

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Nano-Tera.ch: key figures

- **59** Projects (19 RTD – 15 NTF – 19 ED – 6 SSSTC)
- **37** Research institutions (involved with PIs or CoPIs)
- **150** Research groups
- **27** Industrial partners
- **~700** Researchers
- **~120** Doctoral theses supported
- **> 300** Papers published (2010-2011)
- Total Nano-Tera.ch funding support (2008-2011):
  - **60 M CHF** in cash (from Swiss Confederation)
  - **61.8 M CHF** in matching money
- Total funding support for 2012:
  - **15 M CHF** in cash **15 M CHF** in matching support
- Support for 2013-2016 is being negotiated
RTD projects

- Research, Technology and Development projects
  - Multi-discipline projects
  - Multi-institution projects
- Research on fundamental principles
- Applications toward technology demonstrators
- Selected and monitored through the Swiss National Science Foundation
- Budgets around 1MCHF/year (in cash)
- 19 projects currently supported
RTD Projects by themes

19 RTD projects 3-4 years

Health
- NanowireSensor
- NutriChip
- i-IronIC
- CabTuRes
- ISyPeM

Environment
- CMOSAIC
- LiveSense
- GreenPower

Security
- QCrypt
- IrSens
- Nexray
- TecInTex

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Consortium institutions

Leading House
EPFL Swiss Federal Institute of Technology Lausanne

Consortium
CSEM Swiss Center for Electronics and Microtechnology
EPFL Swiss Federal Institute of Technology Lausanne
ETHZ Swiss Federal Institute of Technology Zurich
UniBas University of Basel
UniGE University of Geneva
UniNE University of Neuchâtel
USI University of Lugano

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37 participating institutions
Distribution of research groups

150 research groups

37 institutions
Distribution of research groups

150 research groups
37 institutions

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E-Health

Objectives:
- Advanced diagnostics and prevention
- Clinical and pharmacological assistance
- Wellness for everyone

Innovation areas:
- Real-time accurate sensing - In body, on body, off body.
- Information transmission and networking - Body area networks
- Data elaboration, retrieval and classification - Specialized algorithms and software
- Security and safety

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**Goal:**
Study an innovative • multi-metabolites • highly integrated • fully implantable • real-time monitoring system for human metabolism

Currently available wearable systems for health monitoring are for glucose

Many different molecules are crucial to monitor: lactate, ATP, cholesterol

**Breakthroughs**
- Fully implantable sensor system
- Multi-panel sensors to sense several metabolites (lactate, cholesterol, ATP, etc.) in parallel, in real-time
- New design for fully-implanted, complex and low-power electronics for sensing and with remote powering

Cylinder: about 2 mm in diameter and below 20 mm in length
Medical platform design

- Specific components
  - Probes and electrodes
  - Chambers and fluidic circuits
- Electronic components
  - Transconductance amplifier and data conversion
  - Transmission and powering

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Enhanced nano-bio-sensing
Increased sensitivity

Sensor sensitivity is enhanced by nano-structuring the electrodes

C. Boero, S. Carrara et al., IEEE PRIME, 2009
Systems considerations

- Multi-panel real-time sensing
  - Use sensor array to do multiple bio-measures, along with temperature and pH sensing
- Low-noise transconductance amplification
  - Low-power operation
- Data and power transmission
Other sensing platforms

- **LiveSense**: *Philippe Renaud (EPFL)*
  - Use living cells, fed by supply, to sense
  - Optical and electrical monitoring
  - Target: toxic compounds in water

- **IRSense**: *Jerome Faist (ETHZ)*
  - Use near-infrared absorbance measures
  - Target: organic compounds in fluids

- **NanowireSensor**: *C. Shönenberger (U. Basel)*
  - ISFETs based on silicon Nanowires
  - Non-labeled sensing

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Technology integration into textiles: empowering health

Gerhard Tröster (ETHZ)

Sensing capabilities close to the human body → monitor activity, motion, health...
Incorporate built-in technological elements in our everyday textiles & clothes
Existing E-textiles: low processability, wearing comfort, washability...

- design & manufacture truly wearable functional clothes
- electronic fibers
- optical fibers
- transducer between optical & electrical signals

Near infrared spectroscopy sensing
Peripheral vascular diseases: 30% of adults
Early detection possible (near IR spectroscopy), but conventional sensors are cumbersome
Light wearable system in sock to monitor tissue oxygenation continuously & non-invasively

Intelligent underwear for paraplegic people
Pressure ulcers are serious problems for paraplegic and bed ridden patients
→ Build a comfortable device to detect the risk for pressure ulcers in order to enable preventive measures
Weaved optical sensor design

- Modify optical fibers with sensitive porous layer
  - Specific to biomarkers
  - pH sensors (variation in color)
- Detection based on variation of light absorbance
- Fibers, detectors and light sources into fabric

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Weaved electrical fabric

- Flexible stripes
- Conductive threads for gate control
- Conductive thread for common ground
- LED with TFT

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Weaved electrical fabric
Applications and demonstrators

- NIRS (Near Infrared Spectroscopy) in socks
  - Early detection and treatment of peripheral vascular disease (PVD)

- Intelligent underwear for paraplegic people to prevent and to treat ulcer

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Other medical projects

Monitor knee implants

Mini x-ray sources

Intelligent drug delivery

Organ emulation

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E-Environment
Environment systems

Large-scale distribution of auto-configurable networks of sensor nodes
to sense – network – inform – actuate – interact
with the physical environment, the devices and humans

Next generation information technology, with devices that are:
- highly distributed
- networked
- heterogeneous
- largely self-organizing
- embedded into the environment

Application areas
- Environmental monitoring
- Smart buildings & workplaces
- Smart transportation systems
- Virtual-world applications
Community driven, large-scale air pollution measurement in urban environments

- Important problem: **air pollution**

- **Few monitoring stations** measure pollutants

  - Important technical opportunities & challenges
    - Massive measurements that exploit:
      - wireless sensor networks
      - mobile stations
      - community involvement
    - More data, more noise... also more redundancy
      - Can we produce better quality data?
OpenSense: challenges

**SENSING SYSTEM**
From many wireless, mobile, heterogeneous, unreliable raw measurements ...

**INFORMATION SYSTEM**
... to reliable, understandable and Web-accessible real-time information
Sensing infrastructure

Mobile sensor nodes on public transportation and private mobile devices

Wireless sensing and communication infrastructure
Lausanne: stationary infrastructure

- 2 prototype stationary stations
  - NO2 (2 sensors), CO (2 sensors), Humidity, Temperature
  - Solar panel powered
- 1 station next to Nabel
- 12 stations deployed in 2012

10 m distance result in significant difference

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Lausanne: mobile infrastructure

- 1 prototype station mounted on bus
  - NO2, CO (2 sensors), CO2, Humidity, Temperature
  - Positioning module
  - Powered by bus

- 8 mobile stations being deployed
Lausanne coverage
OpenSense: scientific challenge

Is massive sensing with large numbers of heterogeneous and mobile sensors technically feasible and practically useful?

Use of correlations
Need to compress, clean & interpret the huge amount of data generated
→ Identify and exploit spatial & temporal correlations in sensor data

Mobile sensors
- Intermittent communication
- Sensor position keeps changing
- Need to minimize measurements to reduce power consumption

Community sensing
High public interest
→ Make gathered data available to a large community
With producers of data: reliability and trustworthiness of the information

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Monitoring alpine mass movements at multiple scales

Lothar Thiele (ETHZ)
Anticipation environmental states and risk improved by
- A systematic combination of sensors at different temporal and spatial scale

Wireless Sensor Networks
- Allows us to quantify mountain cryosphere phenomena and their response to climate change
- Can be used for safety critical applications in a hostile environment
X-Sense task structure

Signal Processing
- Precise localization
- SAR – GPS fusion

Wireless Sensor Netw.
- Component-based design
- Application control

Geoscience Modeling
- Spatial analysis
- Model development
- Scenario simulation
Challenge: the physical environment

- Lightning, avalanches, rime, prolonged snow/ice cover, rockfall
- Strong daily variation of temperature
  - $-30$ to $+40^\circ C$
  - $\Delta T \leq 20^\circ C/hour$

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Flexible in-situ exploration (testbed ≠ real system)
- Real sensor data, real environment
- Integration with live data management (system of systems)
GPS measurement devices

Low-cost GPS Devices

- Dual strategy: logging units & wireless sensors
- High temporal resolution
- Accurate displacement-rate of a boulder (mm-cm accuracy for daily position)
GPS deployment: Matter valley

Field Site Inventory
- 9 GPS on composite landslides
- 8 GPS on rock glaciers
- 4 GPS as position reference stations
- 5 simple temperature loggers per GPS station
- 2 Meteo stations
- 1 camera

Installation started August 2010, with full operability in August 2011
X-sense: scientific challenges

- Design, deploy, test sensor nodes
  - Rugged electronics
  - Highly-reliable units
- Gather, fuse data from various sources
  - Algorithms and software for data processing
- Map data onto geological model
  - Correlate physical measurements
- Extract potential alarming situation
Enabling technologies and platforms

- **Enabling technologies** as common research areas to support health and environment application
  - Micro/nano-electronics
  - Sensors
  - MEMS/NEMS
  - Information and communication systems

- **Design platforms**
  - Low power sensing, processing and communication
  - 3-Dimensional integration and packaging
  - Body-area and *ad hoc* networks
Conclusions

- Nano-Tera.ch exploits **new technologies** and devices:
  - *Silicon nanowire* and *carbon nanotube* devices
  - *Integrated electronics* and *sensors*

- With the objective of building **heterogeneous** systems:
  - Monitor health in patients, disabled and elderly
  - Monitor the environment for pollution and to prevent disasters

- And with the final goal of increasing the **security** of individuals and communities
  - Key contribution of engineering to coping with complex societal and economic problems
  - Requiring large and collaborative intellectual effort
Thank you