E-Health
From Sensors to Systems

Giovanni De Micheli
Outline

▲ Introduction
  ▼ Trends in Engineering and Medicine

▲ E-Health
  ▼ Technology issues
  ▼ System issues

▲ Summary, activities and conclusions
The megatrends

▲ Relentless growth of computing, storage and communication technologies
    ▼ Inexpensive terminals providing ubiquitous services
▲ Biomedical science becoming more quantitative
    ▼ Societal need of better care at lower costs
▲ Big data issues fueling research and businesses
    ▼ Models, algorithms, architectures to tame data deluge
The megatrends: IEEE Spectrum
Engineering Trends: The global network

[Courtesy: J. Rabaey]
Engineering trends: The sensory interface

▲ The *More than Moore* revolution:

▽ Low-cost volume production

▽ Direct interface to information processing systems

[Courtesy: ST] [Courtesy: EPFL]
What is health?

State of complex physical, mental and social well-being and not merely the absence of disease or infirmity.
New medical trends: the 4 Ps

- **Predictive medicine**
  - Predict diseases using “omics” technologies

- **Participative medicine**
  - Share data and experiences using social media

- **Personalized medicine**
  - Adapt diagnosis and therapy to individual

- **Preventive medicine**
  - Quality of aging through nutrition and lifestyle
Where medicine and engineering meet

Sequencing

Personalized drugs

Prosthetics and implants
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E-health: objectives

▲ Bettering **medicine** by electronic means
▲ Bringing **low-cost** medicine to the people
▲ Exploiting electronic **well-being** as a **lifestyle**
▲ Opportunities:
  ▼ Synergy of integrated electronic and sensing
  ▼ Platform-based design of electro-sensing systems
  ▼ Mobile telephony as backbone
Point of care

▲ Some molecular tests can be done in real time
   ▼ Efficient and lower cost for routine care
   ▼ Some diagnostics require multiple tests

▲ Emergency situations require real-time measures
   ▼ Patient’s fluids are often connected
   ▼ Local tests and remote diagnosis
Tele-medicine: Monitoring chronic patients

▲ Non-invasive monitors
  ▼ Heart rate, SpO₂, blood pressure

▲ Invasive monitors:
  ▼ Metabolites: glucose, lactate, cholesterol
  ▼ Continuous measurements calibrated in $T$ and $pH$

▲ Wireless challenges
  ▼ Secure transmission
  ▼ Remote powering
Examples

Prototype for human implant [EPFL]

GLUCOSE SENSOR [Senseonics™]

Muti-sensor for lab animals [EPFL]
Examples

Muti-sensor for lab animals [EPFL]
Tele-medicine
Remote ultrasound diagnosis

▲ Portable ultrasound head & processor
▽ Untrained operator acquires 3D volumes
▽ Beamforming, compression and transmission
▽ Radiologist/Sonographer evaluates images remotely

New 2D probes for 3D image acquisition
New low-power, low-cost hardware design
Image reconstruction, rotation & sectioning
Challenges:
Remote ultrasound diagnosis

▲ 3D Ultrasound imaging requires supercomputing:
   ▽ TB/sec of bandwidth, GB of storage and TOP/sec
▲ Electronics should be confined in small volume
   ▽ And directly integrated with the probe
▲ Wide space of applications, modes and parameters
Therapeutic Drug Monitoring (TDM)

- Drug dosage according to the individual pharmacokinetic profile
Drug concentration in blood

- $C_{\text{max}}$
- Duration of action
- Therapeutic Range
- AUC
- MTC
- MEC
- Onset time
- $t_{\text{max}}$
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Technologies

▲ Sensing
  ▶ Electrical, mechanical, optical

▲ Fluidics and transducers
  ▶ Micro tubes, valves, pumps

▲ Data acquisition electronics
  ▶ Discrete, integrated, monolithic with sensor

▲ Packaging
  ▶ Rigid/flexible, bio-compatible
The platform and its components

▲ Electro-chemical sensors for families of targets benefit from modular integration
  ▽ Similar scalable geometries
  ▽ Different molecular functionalization
  ▽ Different I/V response

▲ Components can be stored in a cell library
  ▽ Semicustom approach
Platform design example

Constraints

▲ Compact
▲ Biosensor array
▲ pH control
▲ Temperature control
▲ IC integration
▲ Easy Fabrication
▲ Biocompatible

Solutions

Key points

▲ Co-design of electronics and sensing is key
  △ Achieve low-power consumption
  △ Achieve small footprint

▲ Platform-based design
  △ Modularity of design is key to reducing NREs

▲ Electronic technology can be extended upwards
  △ Monolithic integration
  △ Silicon interposer technologies
Monolithic and TSV-based integration

[Schienle et al., JSSC 2004]

[Temiz et al., El Letters 2011]

[Temiz et al., Lab on Chip 2012]
CMOS-compatible nanostructuring

▲ Electrode nano-structuring on top of CMOS
▼ Increases sensitivity and lowers LOD
▼ Carbon structure growth at 450°C in two steps

1st CVD growth

2nd CVD growth

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System-level challenges

▲ Correctness:
   ▼ The system must perform its function in any condition

▲ Security:
   ▼ No medical information leaking to other parties
   ▼ No access from non-authorized sources

▲ Safety:
   ▼ Under no condition the health-device can be a threat
   ▼ Safety must be guaranteed for both patient and operator

▲ Dependability:
   ▼ All devices must work long time in possibly harsh condition
   ▼ Graceful degradation mechanisms

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Correctness

▲ Diagnostic systems
    ▼ Accuracy, linearity, limit of detection

▲ Drug administration decision support systems
    ▼ Decisions based on acquired data must be correct

▼ Life-critical systems

The verification problem

▲ Verify that a therapeutic protocol is
   ▼ Consistent
   ▼ Complete

▲ Verify that a drug administration control unit is a correct *implementation* of the protocol
   ▼ Model checking
Formal model of Imatinib protocol

Advantages of formal models

▲ Reason about properties in a formal way
   ▼ Check for invariants

▲ Synthesize optimal control policies for drug administration
   ▼ Sequence of (time, dose)

▲ Golden model to verify hardware implementation
Key points

▲ Very few protocols have a formal description
  ▼ Corner cases are hazardous for patients
▲ Personalization of drug dosage is important
  ▼ But still used in few cases
▲ Modeling human body reaction is critical
  ▼ But often hard to achieve in a deterministic way
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Summary: Opportunities and challenges

▲ E-health is an unstoppable life-changing trend with unlimited possibilities
▲ The market is articulated:
   ▼ Some areas are harder than others to penetrate
   ▼ Many problems are still not well understood
   ▼ Ethics and regulations play a major role
▲ Exciting field for researchers and developers
Nano-Tera.ch

160 research groups
38 institutions
15 MCHF/year – 9 years
Some Nano-Tera.ch success stories

- Smart sensor-equipped textiles, able to monitor tissue oxygenation
- Optical sensing platform to detect doping agents in saliva
- Wearable ECG with wireless data transmission
- Integrated neuroprosthesis for motor control & recovery after spinal cord injury
- High accuracy surgery for minimally invasive interventions of the ear
- Monitoring obese patients via sensors integrated into smart textiles

[http://www.nano-tera.ch/]
Conclusions

▲ New electronic health systems and services will be enabled by advances in biology and medicine, in combination with progress in electronics

▲ The rationalization of health care will provide advanced care to a broader audience at lower cost

▲ Human factors will still be central to decisions in medicine - decision support will be automated
Thank you
Thank you