Trillion Sensor Technology
Engineering for the Public Good

Albert P. Pisano
Dean, Jacobs School of Engineering
University of California, San Diego

Distinguished Professor,
Mechanical and Aerospace Engineering
Electrical and Computer Engineering
Member, National Academy of Engineering

DeanPisano@eng.ucsd.edu
World-Class Engineering School

UC San Diego Jacobs School of Engineering

13th in the World for Engineering, Technology & Computer Science
Academic Ranking of World Universities, 2013

8th among U.S. best public engineering schools
U.S. News ranking of graduate schools, 2013

1st in the U.S. for biomedical engineering
National Research Council, 2010
Introduction to Abundance*

Abundance* movement forecasts elimination in one generation (20 to 30 years) of major global problems:

- Lack of food
- Lack of medical care
- Lack of clean water and air
- Lack of energy

Abundance forecasts the need for (among others) 45 trillion sensors, many not yet developed.

Historical sensor development cycles from prototypes in academic labs to volume production were 30 years.

- Left to historical cycles, slow new sensor commercialization would delay the arrival of Abundance.

Trillion Sensors Movement encourages the acceleration of the new sensor development cycle.

* http://www.abundancethebook.com/
Abundance* Enablers

Exponential Technologies that Promise to Grow Into Large Markets Quickly

- Biotechnology and bioinformatics
- Medicine
- Nanomaterials and nanotechnology
- Networks and sensors (45 trillion networked sensors in 20 years).
- Digital manufacturing (3D printing) and infinite computing
- Computational systems
- Artificial intelligence
- Robotics

* http://www.abundancethebook.com/
Bill Gates: No Poor Countries by 2035

The world’s poorest countries

World Bank classification, based on gross national income per capita

- High-income
- Upper-middle-income
- Lower-middle-income
- Low-income
- No data

Quartz | qz.com

Data: World Bank

Engineering for the Public Good

UC San Diego Jacobs School of Engineering

Medical Advances

Sustainable Energy Technologies

Transportation Safety

Solutions for Developing World
Cluster Sensor Landslide Prediction

UC San Diego Jacobs School of Engineering

Landslide Sensor Rod Concept

Installation:
The sensor rod is driven into the ground by conventional, hydraulic ground driving methods that are fast and cost-efficient.

Operation:
Each segment of the sensor rod is equipped with a sensor cluster bonded to the outside of the rod and a small frontend circuit inside the rod.

Initially, the sensor rod forms a solid unit that is very stiff to the axially applied driving forces. The landslide sensor clusters on the sensor rod are specifically designed to survive the large shock forces from the installation.

The combined data from all sensor clusters gives a complete picture of the ground conditions and the likelihood of an impending landslide.

A brief pull on the sensor rod finalizes the installation process.

The jointed segments allow the individual segments to move independently.

The axial pull engages the anchor at the end of the sensor rod to secure the rod in the ground.

Any ground movement can be monitored with high horizontal and vertical resolution and accuracy.

The joints between individual segments of the sensor rod are freed simultaneously by the axial pull.
Epidermal Electronics: Just a Tattoo?

UC San Diego Jacobs School of Engineering

Todd P. Coleman, Ph.D.
Department of Bioengineering

Science, Aug 12, 2011.
Whole Body Wearable Sensors

UC San Diego Jacobs School of Engineering

Fitness Textile Sensor

Epidermal pH Sensor

Metabolite Sensor with Electronics

Forensic Finger Sensor

Any-place All-day Non-Invasive Monitoring directly on the Skin or Textile:
Reduce health-care costs and enhancing the quality of life.
American bioengineers have demonstrated that an implanted glucose sensor with potential to transform the management of diabetes has passed a crucial test: the device they developed worked continuously in animals for over a year, without showing signs of "tissue encapsulation" seen in trials with other similar devices. 2010.
E4E Technology

UC San Diego Jacobs School of Engineering

**Land**
- Intelligent Camera Trap
- Terrestrial Vehicle

**Air**
- Stabilized Aerial Platform
- Unmanned Aerial Vehicle
- Multi Rotor Vehicle
- BirdCam

**Sea**
- Stingray Autonomous Underwater Vehicle
- CoralCam
E4E Applications

Whale Shark Monitoring

Goal: Classify the world's largest, yet illusive fish
Partner: Hubbs SeaWorld Research Institute

Underwater Archeology

Goal: 3D reconstructions of underwater archeological sites
Partner: Atlantic World Marine Archeology Research Institute

Habitat Restoration

Goal: Understand and track health of river valley
Partner: San Dieguito River Valley Conservatory

Protecting Vaquita

Goal: Conservation of world's most endangered cetacean
Partner: San Dieguito River Valley Conservatory
CitiSense: Air Quality via the Crowd

UC San Diego Jacobs School of Engineering

- Mobile personal sensing approach to regional air quality monitoring
- Machine learning latent-variable analysis interpolates between sensors & predicts future conditions
- Two month-long user deployments in San Diego region
- Other contributions
  - End-to-end Hardware/software system design
  - Mobile power management
  - Interaction design for in-the-world sense-making
  - Observed new patterns of sense-making, behavior, attitudes, sharing

Griswold, Dasgupta, Krueger, Rosing (CSE), Patrick (SOM)
Objective: To restore vision from irreparable rod and cone damage related to various forms of degenerative retinal disorders such as Macular Degeneration.

Our Solution: To restore vision from implantation of photosensitive semiconductor nanowires serving the functions of photoreceptors to stimulate neural responses of ganglion cells that transmit image signals to the brain through the optical nerve.
Implantable Nanowire Photoreceptors

UC San Diego Jacobs School of Engineering

Human Photoreceptors in Combs
Arrays of Si nanowires
Human neurons on Si nanowires

Nanowire prosthesis in the eye

Stimulated neural signal by Si nanowires
Enzymes enable powerful therapies against cancer: they can revolutionize selectivity of chemotherapy or starve cancer by depleting tumor nutrients (Licensed to Devacell Inc.)

However, most therapeutic enzymes are unstable and from non-human origin therefore immunogenic

Dual porosity SHELS platform offers an engineered nanotechnology solution

Engineered nano-teabag:
Encapsulated enzyme is larger than the nanopores but smaller than patterned holes. Pro-Drug, drug and amino acid molecules are small enough to pass through the porous shell and cleaved by the enzyme. Hole refilling chemistry does not affect enzyme function

In Vivo Proof of concept:
Pancreatic tumor cannot grow when IM injected, asparaginase loaded SHELS distant from tumor depletes serum asparagine (Left).
Encapsulated asparaginase achieve systemic aminoacid depletion in the presence of neutralizing antibodies while bare enzyme completely fails
Toxin Nanosponge

**UC San Diego Jacobs School of Engineering**

The nanosponge is a biocompatible particle made of a polymer core wrapped in a red blood cell membrane. It is capable of safely removing a broad class of dangerous toxins from the bloodstream regardless of the toxin’s molecular structure.

In *vitro* test-tube hemolytic assay (effectively protects RBCs)

*In vivo* bloodstream detoxification (89% survival from lethal doses of toxins)

*Nature Nanotechnology* 2013, 8, 336-340 (Liangfang Zhang Laboratory).
Printable Nanoelectronics

UC San Diego Jacobs School of Engineering

Quality nanoparticle (NP) generation via microreactors

Generation of Ink (choose solvent, ligands, etc.)

Nanoprinting

Several Applications

MEMS SAW Devices

UV Sensors

Organic Electronics

E. Erdem, et al., Small, 2013, in press
M. Demko, et al., ACS Nano, 2012
Next Wave: Advective Nanoprinting

UC San Diego Jacobs School of Engineering

<table>
<thead>
<tr>
<th>Multiple Layers</th>
<th>Resolution: 250 nm</th>
<th>Alignment: 100 nm</th>
<th>Throughput: Moderate</th>
</tr>
</thead>
</table>

Mold

Nanoparticle or Polymer Ink

Solvent Vapors

Substrate

Clean Solvent

Evaporating Solvent

Liquid Solvent

Gold Nanoparticles

Dry Nanoparticle or Polymer Lines
Key Advantages

UC San Diego Jacobs School of Engineering

Cellulose Acetate on Polyimide

Gold Nanoparticles on Glass

Large Area
No Residual Layer

With Each Print:
High Aspect Ratio
High Geometry Fidelity
Tall Features in Single Shot

PMMA on Silicon

M. Demko, et al., Langmuir, 2010
Additional Advantages

UC San Diego Jacobs School of Engineering

Cellulose Acetate and ABS

Cellulose Acetate and PMMA

Multiple Materials Printed Concurrently

Chitosan on Glass

Gold Nanoparticles on Polyimide

Zinc Oxide Nanoparticles on Silicon

Compatible with Large Number of Different Substrates

M. Demko, et al., APL, 2011
Benefits of Higher Local Rigidity

UC San Diego Jacobs School of Engineering

Micro-scale Patterns of Cellulose Acetate on Silicon

M. Demko, et al., ACS Nano, 2012
3D Bioprinting for Tissue Engineering

UC San Diego Jacobs School of Engineering

• Develop 3D bioprinting techniques integrating biomaterials/nanomaterials, optics, and stem cells
• Create patient-specific live tissues for repairing heart, liver, eye, and spinal cord injury.
• S. Chen - NanoEngineering

3D-printed biomimetic conduits for repairing spinal cord injury

3D-printing of vascular-like hydrogel in 1 sec
Invitation to San Diego

UC San Diego Jacobs School of Engineering

RESEARCH EXPO
April 17, 2014

Get Inspired
230+ Research Posters

Technology Roadmap
Ted-Style Talks by World-Renown Faculty

Connect with Engineers
500+ Students, Alumni, Industry, Faculty

www.JacobsSchool.ucsd.edu/re
Invitation to San Diego

UC San Diego Jacobs School of Engineering

The TSensors Summits (www.TSensorsSummit.org) are a forum for the world’s sensor visionaries to present their views on which sensor applications (TApps), sensor types and manufacturing platforms have the potential to fuel market growth to the trillions of units within a decade. Such forecasted explosion will be a continuation of consumer sensor growth from 10 million units in 2007 (iPhone introduction) to almost 10 billion devices in 2013.

Co-Chairs of TSensors Summit, San Diego:
- Albert P. Pisano, Dean of UC San Diego Jacobs School of Engineering
- Dr. Janusz Bryzek, originator and Chair of TSensors Summit movement

Register Here

Participation limited to 400 registrants. All TSensor Summits have reached full capacity, please register early.


Contact Bette Cooper at bcooper@tsensorssummit.org, 650-714-1570. For more information and to add your e-mail address to our distribution list please go to www.tsensorssummit.org and click on “Join Our Email List”.

Premier Sponsor for TSensors Summit San Diego

[Image of sponsor logos]
Conclusion

Thank You!

Albert P. Pisano
Dean, Jacobs School of Engineering
University of California, San Diego

DeanPisano@eng.ucsd.edu
+1 (858) 534-6237
www.JacobsSchool.ucsd.edu