Sensors for the Internet of Things

Making the “things” connectable.

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INTERNET OF THINGS: TECHNOLOGIES ENABLING THE REVOLUTION
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The Internet of Things
Revolution in technology

Important developments

- Extreme miniaturization and commoditization of electronics
- Global telecommunications infrastructure
- Massive acceptance of technology

Impact

Completely new classes of products and ways we work, play, communicate, think. Technology is a commodity, cheap and ubiquitous.

This is an historic situation.
Times are changing...

Today:
The Internet of People
Most data generated by/for humans

Tomorrow:
The Internet of Things
Most data generated by/for things
The “Internet of Things”

What does the world mean to this interconnected world?

- By 2020, the Internet of Everything expected to connect 50B.
- Triple digit growth: Energy, Transportation, Digital Cities, Healthcare, Financial Services, Retail (Verizon)
- “…a $19 trillion opportunity” (John Chambers, Cisco CEO)
- Big winners: semiconductor, network, remote sensor and big data

50 Billion devices by 2020

= 650 Million devices/month

The future’s in the air; I can feel it everywhere; Blowing with the wind of change.

- The Scorpions
IoT Entry Points

- **Applications**
  (connecting things to the internet)

- **Analytics and data integration**
  (enterprise systems, big data, databases)

- **Cloud services**
  (hosted apps, web, security, SEO, e-commerce)

- **Telecommunication services**
  (cell access, internet service)

- **Servers, data storage**
  (servers, hard drives)

- **Wireless systems**
  (short range communications, routers)

- **Embedded electronics**
  (microcontrollers, microcomputers)

- **Physical interfaces**
  (sensors, controllers, actuators, effectors)

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**IoT “Front End”**
Physical interfaces, embedded electronics, wireless (the front end of IoT)

**Physical interface modules:**
sensors, controllers, actuators, effectors

*IoT expected to be one of the major drivers of sensor market in coming decade!*
Physical interfaces, embedded electronics, wireless (the front end of IoT)

**Products**

- Physical Interface Modules (PIMs)—sensors, controllers, effectors, actuators.
- Embedded electronics
- Radios, hubs, routers, modems, micro-servers
Servers and telecommunications
(the backbone of IoT)

Products

• Servers, server farms
• Data storage, retrieval systems
• Security, encryption products
• Wide area networks, cell coverage
Cloud services
(the brains/back end of IoT)

Products
• Cloud services, cloud computing
• SEO, e-commerce
• Big data, analytics
Applications
(the value of IoT)

Applications
• Systems integration of all technologies in IoT
• Requires breadth and depth, strong team
• ROI can be high, with ongoing revenue after initial work
• Dependence on ability to get customers and solve their needs
Highest value—The “killer apps”

Full systems for end-to-end integration
Sensors for IoT

The TOP 13 most important sensors for IoT...
(according to Mark)

The front end of IoT
Physical interfaces, embedded electronics, wireless
(the front end of IoT)

1. Inertial sensors
   • Applications: Industrial machinery, automotive, human activity
   • Technology: MEMS

8. The EU-funded microscopic-sized gyroscope DAVID (Downscale Assembly of Interconnected Devices) project focuses on developing an inertial sensor system with extremely high packaging density for the hybrid integration of MEMS and ASIC devices.
Physical interfaces, embedded electronics, wireless
(the front end of IoT)

2. Tachometer sensor
   • Applications: Industrial machinery, automotive, human activity
   • Technology: Magnetic, light
Physical interfaces, embedded electronics, wireless
(the front end of IoT)

3. Proximity sensor
- Applications: Industrial machinery, automotive, human activity
- Technology: Capacitive, Inductive, Magnetic, Light, Ultrasound
4. Occupancy sensor

- Application: Home/office monitoring
- Technology: Passive IR, Ultrasound most common
Physical interfaces, embedded electronics, wireless (the front end of IoT)

5. Temperature/humidity sensor
   • Applications: Home/office HVAC control, automotive, industrial
   • Technology: Solid state, RTD, thermocouple
Physical interfaces, embedded electronics, wireless
(the front end of IoT)

6. Light sensor
- Applications: Home/office/industrial lighting control
- Technology: Solid state, photocell, photoresistor, photodiode
- Cadmium sulphide (CdS) and Cadmium Selenide (CdSe)
7. Power (current) sensor

- Applications: Home/office/industrial power monitoring/control
- Technology: Coil (Faraday’s law), Hall effect
Physical interfaces, embedded electronics, wireless  
(the front end of IoT)

8. Moisture sensor

- Applications: Agricultural irrigation monitoring/control
- Technology: Capacitive, RF pulse, (also: thermal, resistive)
Physical interfaces, embedded electronics, wireless
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9. Touch sensor

- Applications: Human interface
- Technology: Capacitive, Resistive
10. **Pressure pad sensor**

- **Applications:** Human interface/monitoring, industrial
- **Technology:** Piezoresistive, capacitive
Physical interfaces, embedded electronics, wireless
(the front end of IoT)

11. Air/fluid pressure sensor

- Applications: Industrial monitoring/control, automotive, agriculture
- Technology: Diaphragm, condenser
12. Acoustic sensor

- Applications: Industrial monitoring/control, human interface, nautical
- Technology: Diaphragm condenser, SAW
13. Strain sensor

- Applications: Industrial monitoring/control, civil infrastructure
- Technology: Resistive thin films
Anatomy of an IoT module

1. Sensor(s)
   Interface to world
2. Computer
   Smart
3. Memory
   Allows telemetry
4. Wireless / telemetry
   Communications
5. Power
   Power management
6. Support electronics
   Amplification, filtering

TOO BIG and EXPENSIVE
Anatomy of an IoT “chip”

“System in Package”

- Sensor(s)
- Computer
- Power
- Support
- Memory
- Wireless
The future of IoT devices: System in Package

“System in Package”

Everything in one small package
System in Package requires **Heterogeneous Integration**

- Precision manufacturing, multiple materials, multiple technologies
Some System in Package enabling technologies

1. Thru-Silicon Vias (Interposers)
   *Enables 3-D stacking of chips*

2. Redistribution Layers
   * Enables trace routing*

3. Thermal management components
   * Enables heat management and removal*

4. High density connect
   * Enables many data lines to chips*

5. Antenna on package
   * Enables wireless communication*

6. Advanced substrates
   * High speed communications*

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- radio chip
- micro controller
- humidity sensor
- antenna
Sensor in System in Package?

✧ Non-standard manufacturing
   Many sensors not standard solid state, often with specialty materials

✧ Special packaging requirements
   May require environmental access, hermetic seals, low temperature...

✧ Fragile components
   Often have free-standing, delicate components

✧ Batch (wafer-level) testing difficult
   Many sensors are not active until after singulation

Hard to integrate in SIP module. Difficult to achieve low manufacturing cost.
Sensor in package...

Crazy Idea:

WHAT IF... We built sensors with packaging technology? Can we combine advanced packaging technology with MEMS techniques.

Benefit:

Get best of both worlds. Develop highly integrated 3-D devices with greater functionality that can be manufactured at low cost. Packaging comes with device manufacture.
Packaging and PCB industries have reached levels of precision suitable for building MEMS devices! They are driven to small size by communications, automotive, computing, and consumer industry.
PCB & Packaging precision/complexity

Source: Yole Development
(via Takashi Kariya)
Value proposition

**New products**
New types of products can be envisioned that can’t be built using silicon, that feature high level of integration, and can be **built with their packages**. Devices can be developed for emerging market of IoT.

**New manufacturing**
New manufacturing methods developed for these applications can be used to create unique capabilities. Manufacturing can produce 3D structures, integration of novel materials, and moving elements. **Packaging is part of the device manufacturing.**

**New business model**
Packaging company can become device company. Sell finished products (or nearly finished products) to end customers. Higher margins, greater differentiation.
Integrated Laminate MEMS

Best of two worlds

Silicon-based Micromachining

Laminate MEMS Technologies

PCB/Packaging Manufacturing

UCIrvine Calit2
Complex microdevices from packaging technology

Drawings taken from US patent / UCI Invention 2006: Bachman, Li
Laminate MEMS microphone

Au Diaphragm Structure, Frontside Port

Backside Port

Panel-level fabrication in commercial PCB fabrication shop (TW). Excellent quality of work.
Acoustic substrate (sensor substrate)

Benefits for embedded MEMS in Substrate

- Multiple sensors (e.g., array) without increase in footprint
- Space saving, leave room for electronics
- Larger sensing area possible
- Thinner profile
- More integration
Latching magnetic MEMS switch

Top latching

12 layer EM coil

Magnet

Spring

Spacer

Transmission Line

Bottom latching

Magnet + Silicone header

Polished Transmission line

Spring/pad assembly EM coil add on
MEMS switch handles high power and voltage

World Record!
Our MEMS DC switch 3x3 mm (packaged) can handle more than 50 watts of power at 110 VAC. Instantaneous power is 100 W. That is more than 20 times the best silicon device.

This is the ONLY low voltage actuation, high power latching MEMS switch.
Universal IoT System/Sensor in a Package

The ultimate integrated system in package!
New advancements in sensor packaging will be needed to bring the cost of sensor systems (PIMs) down.

New methods of manufacturing sensors and actuators can be explored to produce smaller, less expensive sensor components.

Packaging is a viable manufacturing technology for building sensors and actuators. **Packaging manufacturers could become device manufacturers.**
There’s a storm coming

It’s going to rain money...
But I can’t tell you where to put your bucket.
You must ride the wave.
But you don’t have to ride alone...

Come to Southern California. Let’s collaborate.
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