

Part I Outline

- Module 1: Introduction to IoT
 - A Motivating Example
 - IoT Concept
 - IoT Trend
 - **IoT Applications**
 - IoT Application Enablers
 - IoT Challenges
- Module 2: General Network Architecture for IoT
 - IoT Network Architecture
 - 3-Layer Model: Functional Stack, Compute Stack
 - Cloud Computing
 - Communications with Cloud: HTTP, REST, CoAP, MQTT
- Module 3: IoT Devices
 - Sensors and Actuators
 - Connected Smart Objects
 - IP as the IoT Network Layer
 - Information Acquisition

Related Areas

- **Embedded systems:** not necessarily connected
- **Sensor networks:** collection of sensor devices connected through wireless channels
- **Cyber-physical systems:** focus on interaction between physical and cyber systems
- **Real-time systems:** focus on time constraints
- **Pervasive/ubiquitous computing:** focus on anytime/anywhere computing

Related Areas (cont'd)

- **Machine-to-machine (M2M) communications:** only focus on data communications
- **Artificial intelligence:** centralized and distributed AI for decision making



Skynet (Terminator)

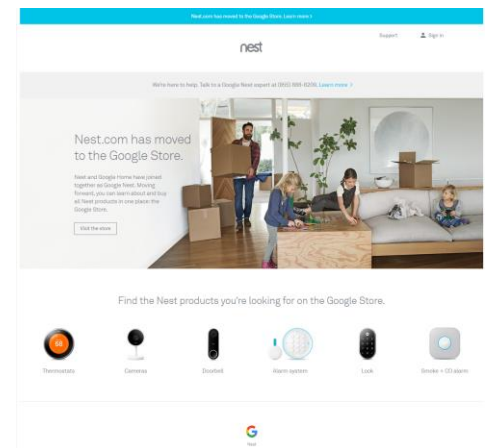


V.I.K.I. (I, Robot)

Related Areas (cont'd)

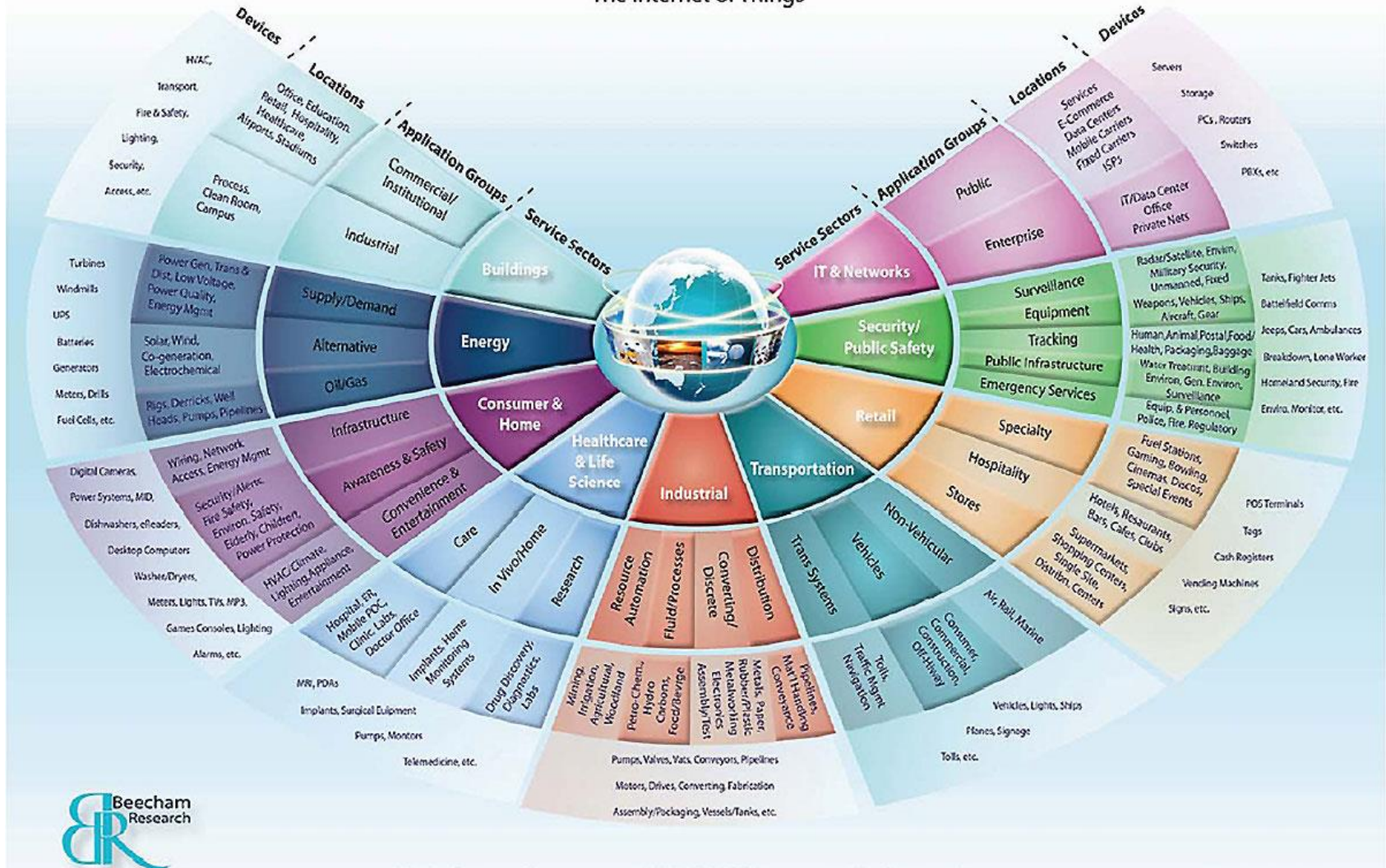
- **Digitization:** as defined in its simplest form, is the conversion of information into a digital format
- Example
 - Whole photography industry has been digitized
 - Video rental with digitization, streaming video content
 - Businesses such as Uber and Lyft use digital technologies
- In IoT, digitization brings together things, data, and business process to make networked connections more relevant and valuable

Google Nest markets smart home products including smart speakers, smart displays, streaming devices, thermostats, smoke detectors, routers and security systems including smart doorbells, cameras and smart locks



IoT Application Domains

The Internet of Things



Example: Connected Roadways

- US Department of Transportation Statistics for 2012:
 - 5.6 million crashes
 - About 31,000 fatalities (26,500 in EU)
 - Over 1.6 million injuries
 - 1 trillion USD in economic loss
 - 5.5 billion hours of travel delays per year
- CO₂ emissions in transportation accounts for **30%** of total US energy-related CO₂ emissions

Example: Connected Roadways – Smart Vehicles

Under the bonnet

How a self-driving car works

Signals from **GPS (global positioning system)** satellites are combined with readings from tachometers, altimeters and gyroscopes to provide more accurate positioning than is possible with GPS alone

- **Lidar (light detection and ranging)** sensors bounce pulses of light off the surroundings. These are analysed to identify lane markings and the edges of roads

Video cameras detect traffic lights, read road signs, keep track of the position of other vehicles and look out for pedestrians and obstacles on the road

Radar sensor

Ultrasonic sensors may be used to measure the position of objects very close to the vehicle, such as curbs and other vehicles when parking

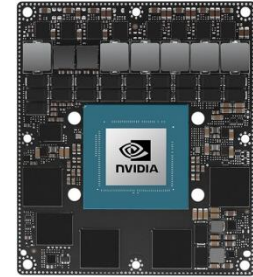
The information from all of the sensors is analysed by a **central computer** that manipulates the steering, accelerator and brakes. Its software must understand the rules of the road, both formal and informal

Radar sensors monitor the position of other vehicles nearby. Such sensors are already used in adaptive cruise-control systems

Source: *The Economist*.

Example: Connected Roadways – Smart Vehicles (cont'd)

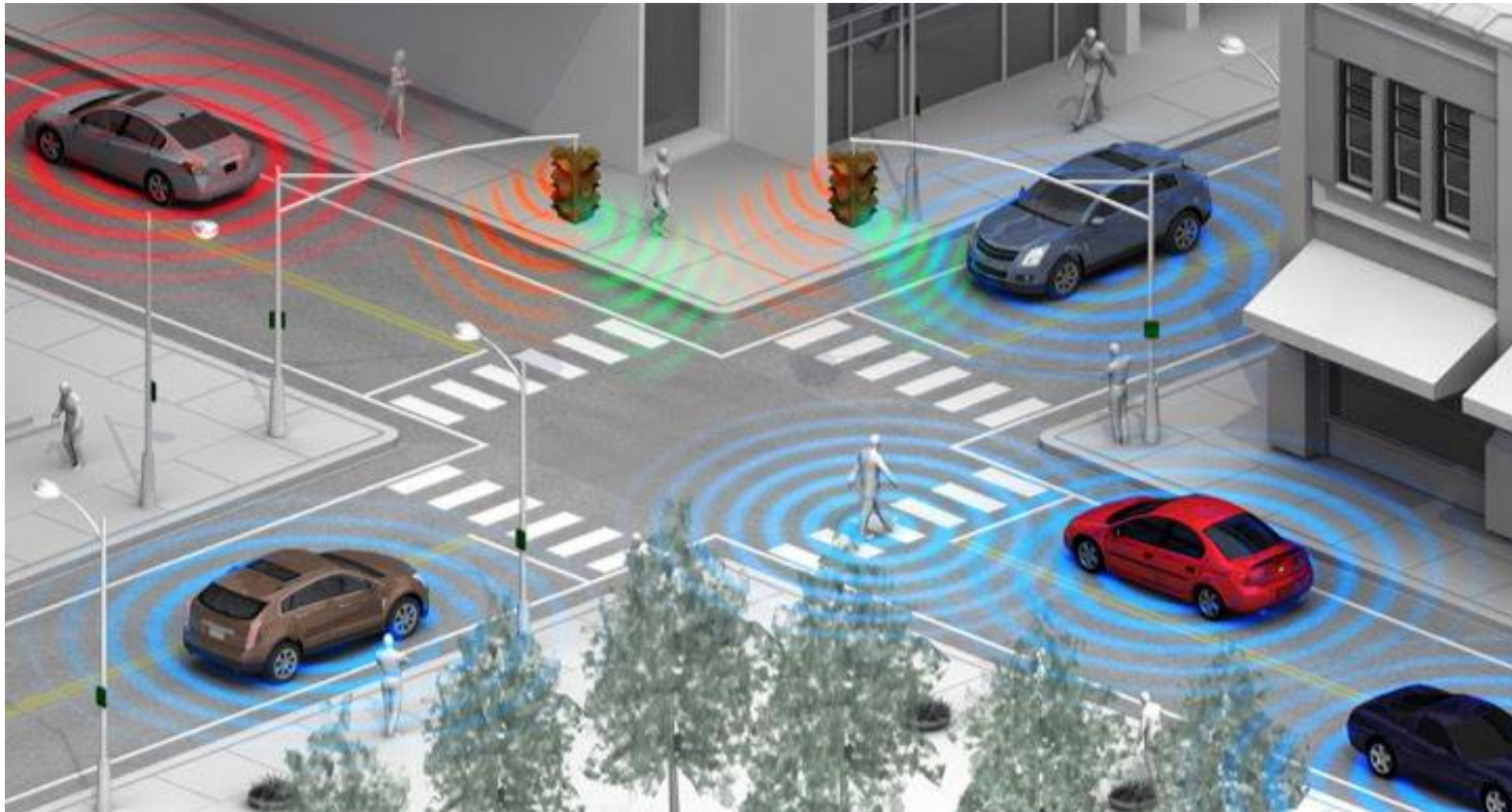
- Increasing computing capability
 - E.g., NIO ET7 (an electric vehicle) has four units of NVIDIA Jetson AGX Orin (embedded GPU)
- Improved network connectivity
 - “The industry is experimenting with rugged eSIMs that can be soldered during manufacturing and configured remotely in position without touching the vehicle.” -- Thales



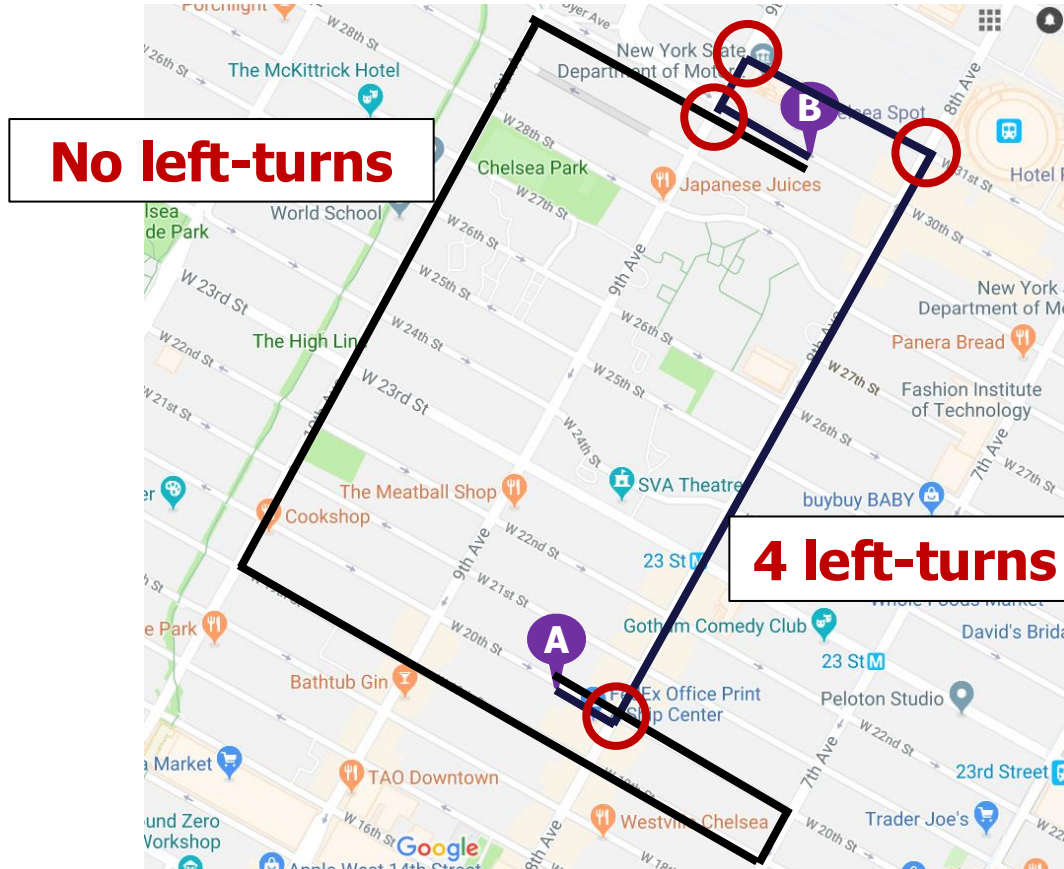
Jetson AGX Orin




Example: Connected Roadways – Smart Infrastructures



Example: Connected Roadways – Smart Routing



10 million
gallons of fuel a year



Example: Connected Factory

The Connected Factory in Action



Example: Connected Factory (cont'd)

- New product and service introductions faster
- Increasing production, quality, uptime
- Mitigating unplanned downtime
- Protecting from cyber threats
- Worker productivity and safety

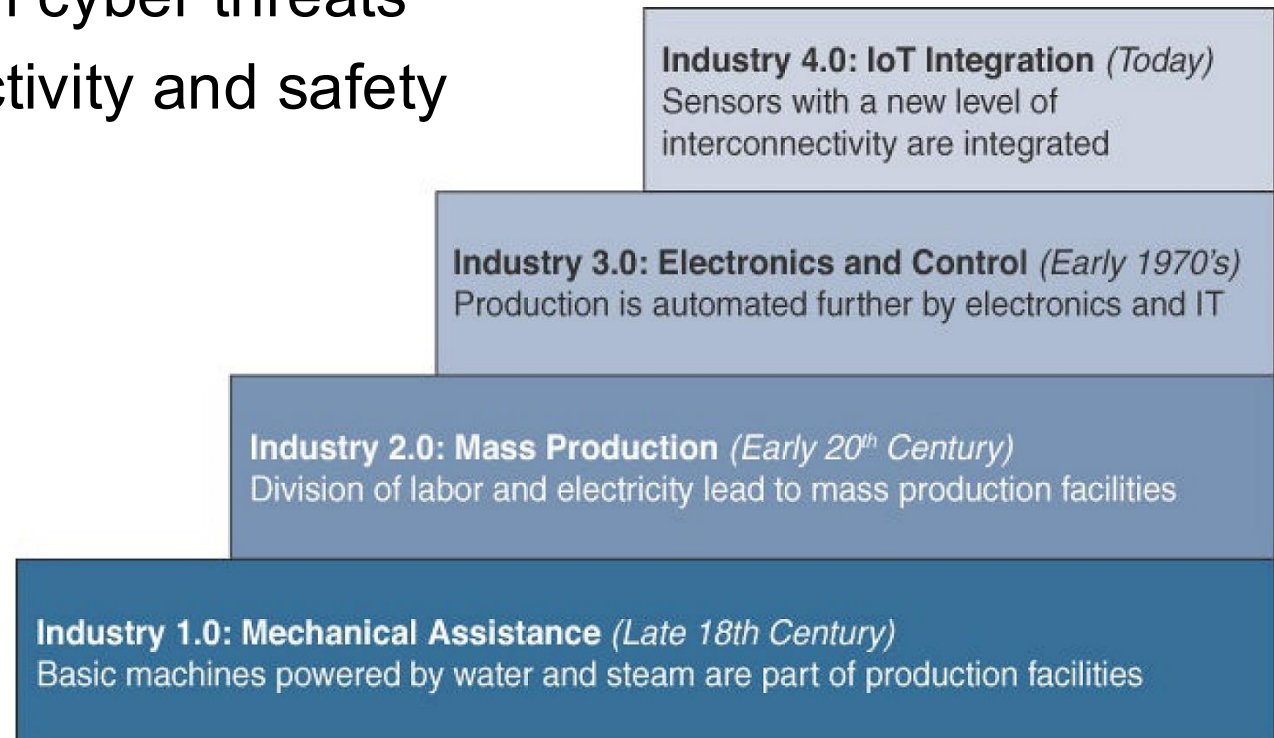


Figure 1-6 *The Four Industrial Revolutions*

Example: Connected Factory (cont'd)

- BubCam: Computer vision-based quality inspection for ink bag manufacturing

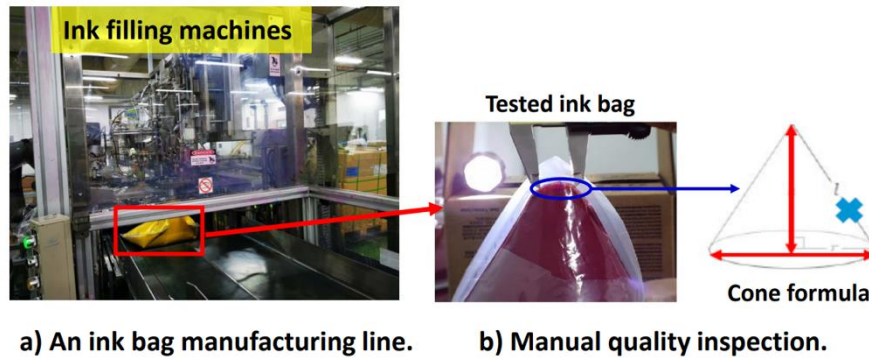


Figure 1: An illustration of factories' manual inspection.

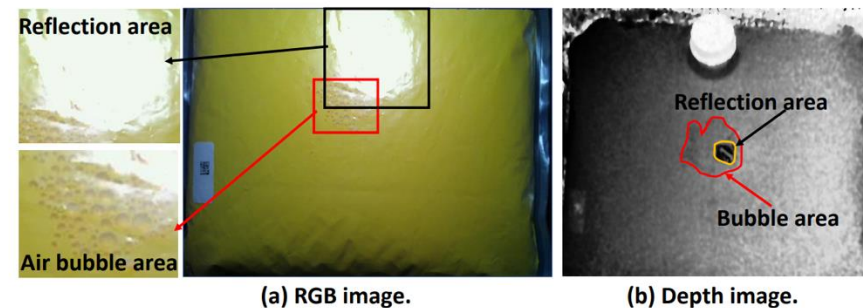


Figure 2: Samples of captured RGB and depth images.

Details: <https://tanrui.github.io/pub/BubCam-ICCPs.pdf>

Example: Smart Building

- Energy management
- Lighting
- Safety
- HVAC
- Building automation
- Smart spaces



NTU to halve carbon emission by 2035

<https://www.ntu.edu.sg/sustainability>

Example: Smart Creatures

Sensorized cow for health monitoring

The connected cow

Necklace

Connecterra, a Dutch company, makes Fitbit-style necklaces that monitor a cow's movement and feeding habits. The sensor can be used to detect health problems and to tell when the cow is in heat, so that insemination can happen at an optimum time.

Acid monitor

Well Cow, a British company, has developed a bolus that is inserted into the cow's rumen to monitor acidity levels. This helps detect digestive problems.

Tail movements

Moocall, an Irish company, makes a birthing sensor that attaches to the tail. It measures tail movements triggered by labour contractions, and sends a farmer an SMS alert approximately one hour before a cow is due to calve.

Pedometer

Afimilk, based in Israel, makes a pedometer for cows. Cows typically increase their walking as they come into oestrus, so the pedometer alerts farmers to the best time for insemination.

'One of the most important issues is to control and increase the quality of milk through IoT'

Udder sensors

Automatic milking systems, such as US-based Lely's Astronaut, can be equipped with sensors to monitor the quality of the milk and check for signs of mastitis.

Picture: iStock

VR relieves cow's anxiety during winter and increases milk productivity by 23%
Aksaray, Turkey, 2021



Example: Smart Creatures (cont'd)

Wireless sensor carried by a bee: a mobile sensing platform



Example: Smart Grid

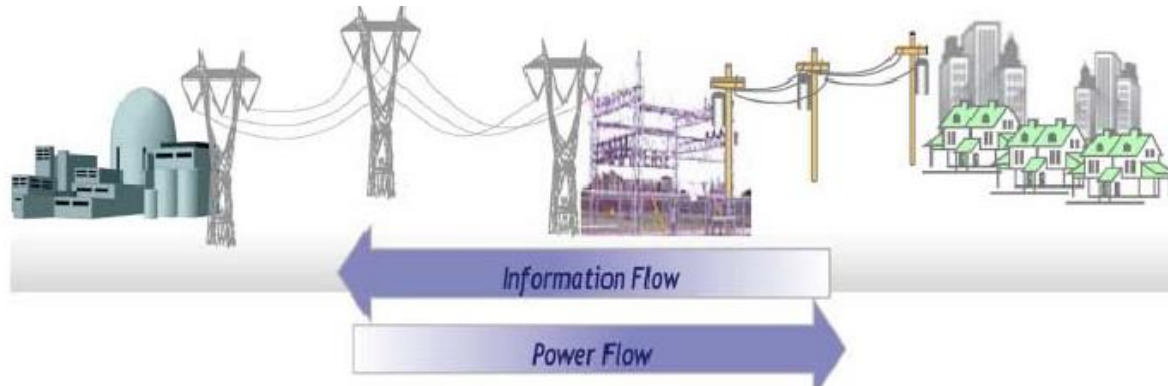


Fig. 2. Power and information flow in the traditional power system environment [13]



Fig. 3. Power and information flow under the smart grid environment [13]

A dedicated lecture on this application

Example: Smart Home



Example: Smart Lighting

- Tunable light, 16 million colors
- Activated by smartphone or over Zigbee wireless
- Can serve as alarm clock
- Can synch colors to movies or possibly music



**Philips never
anticipated the demand
- sold out in 3 months
at Apple stores!**

Example: Smart Shopping

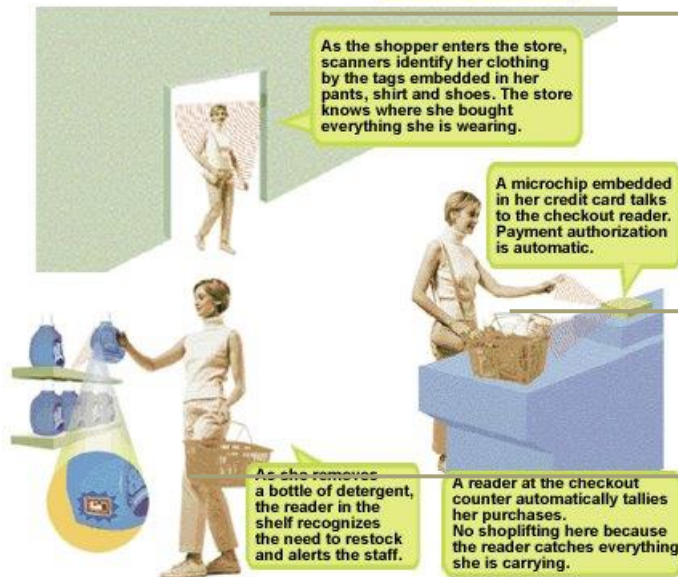
- Bluetooth beacons broadcasting goods info for shoppers to make wise decisions (Dharavi, Mumbai)
 - Google IoT Technology Research Award



Example: Unmanned Mart



(2) When shopping in the market, the goods will introduce themselves.



(1) When entering the doors, scanners will identify the tags on her clothing.

(4) When paying for the goods, the microchip of the credit card will communicate with checkout reader.

(3) When moving the goods, the reader will tell the staff to put a new one.

Illustration by Lisa Knouse Braiman for Forbes

Example: Unmanned Mart

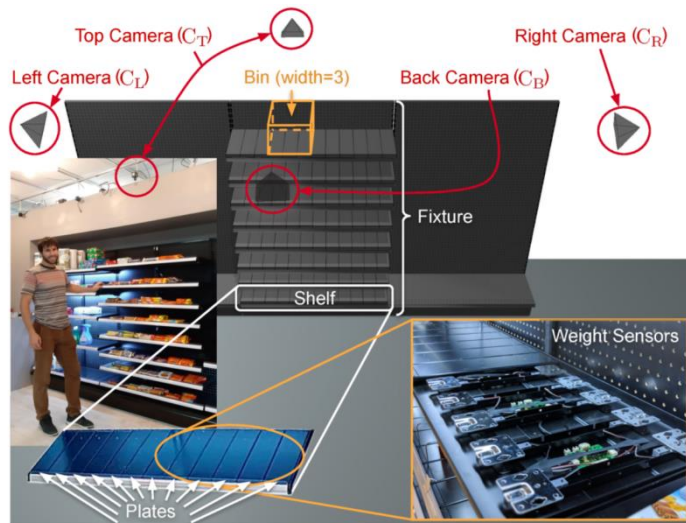
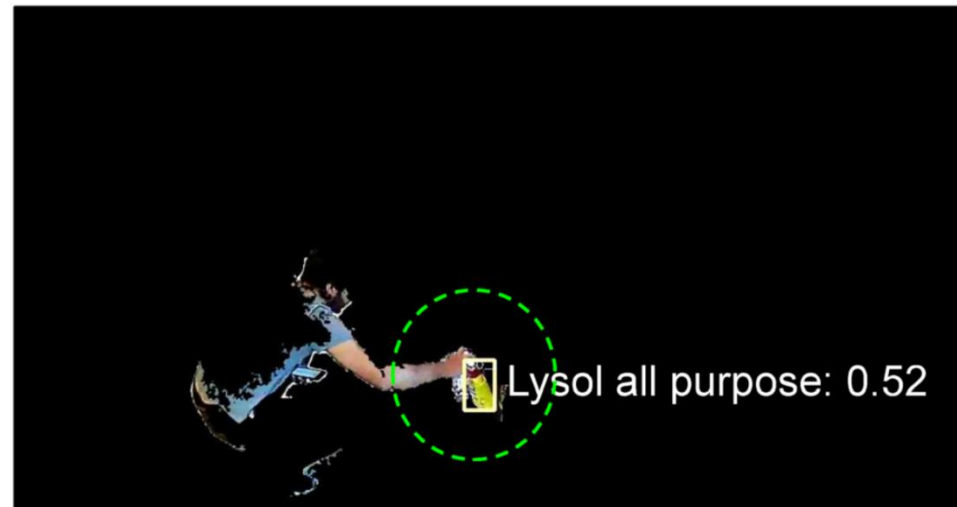


Figure 1: AIM3S scenario and real implementation. Through weight sensors and cameras, the goal is to autonomously detect and identify what item(s) customers take.



Details:

<https://dl.acm.org/doi/pdf/10.1145/3360322.3360834>



Example: Smart Corks

- Smart cork allows wine producers and consumers to have greater assurance of the quality and provenance of each bottle of wine
 - Bottling date
 - Grape type
 - Alcohol percentage
 - and more ...



Example: Smart Health

- Various sensors for various conditions
- Example ICP sensor: Short or long term monitoring of pressure in the brain cavity
- Implanted in the brain cavity and senses the increase of pressure
- Sensor and associated electronics encapsulated in safe and biodegradable material
- External RF reader powers the unit and receives the signal

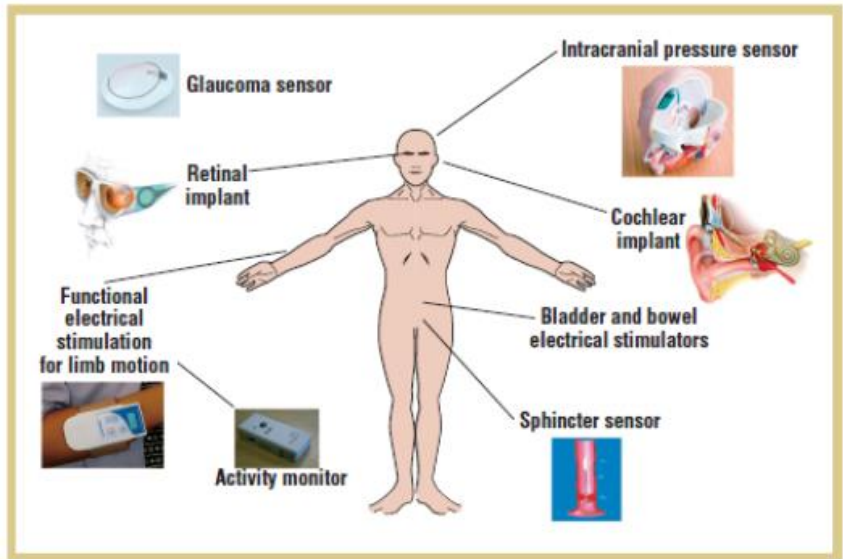


Figure 6. Fully Implantable wireless sensor for the Intracranial pressure monitoring system.

Example: Mobile Health

- RunBuddy: A Smartphone System for Running Rhythm Monitoring

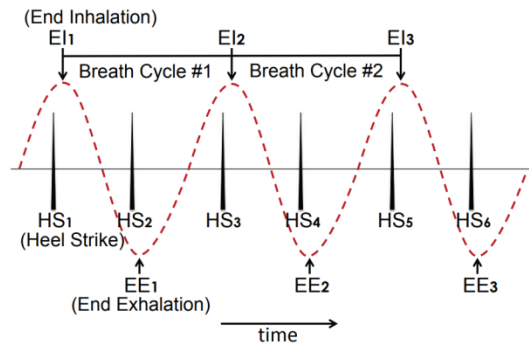


Figure 1. An example of LRC with a 2:1 stride to breath ratio.

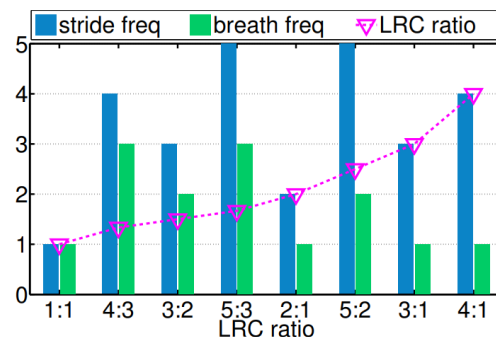


Figure 2. LRC ratios observed in humans while running [38].



Figure 3. A typical setting of RunBuddy. The user is required to wear a bluetooth headset and carry a smart-phone while running.

Details:

https://www.cs.wm.edu/~gzhou/files/RunBuddy_15.pdf

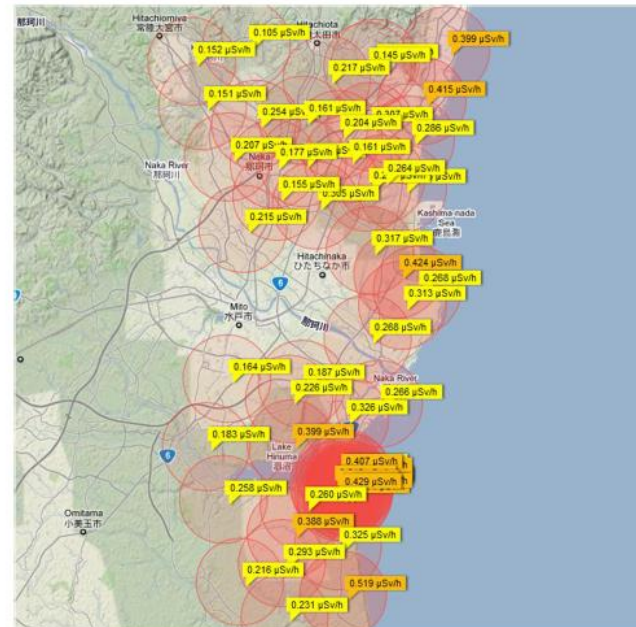
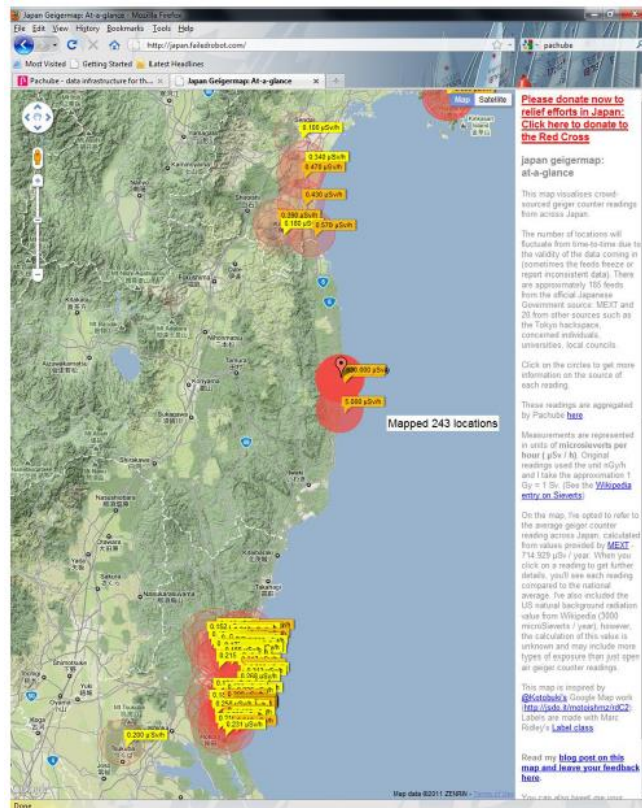
Example: Connected Health Care

- National Health Information Network, Electronic Patient Record
- Home care: monitoring and control
 - Pulse oximeters, blood glucose monitors, infusion pumps, accelerometers, etc
- Operating Room of the Future
 - Closed loop monitoring and control; multiple treatment stations, plug and play devices; robotic microsurgery
 - System coordination challenge
- Progress in bioinformatics: gene, protein expression, systems biology, disease dynamics, control mechanisms



Example: Urban Safety

- After the Fukushima Disaster, many people deployed radiation sensors and joined the Pachube (an real-time IoT data platform)



<http://japan.failedrobot.com/>, 31.3.2011

Example: Urban Safety (cont'd)

- Cool, but
 - Data quality of various sources
 - Accuracy of each data point
 - Sensor reliability and availability
 - Time of measurement
 - Important for trust!
 - Unit jungle:
 - nGy/s, mSv/h, Sv/h, Bq/kg, cpm ...
 - Sometimes misleading, sometimes just hard to compare...
 - Mix of data sources
 - Real sensors
 - Virtual sensors (data scraping from web pages, e.g., <http://www.houshasen-pref-ibaraki.jp/present/map.html>)

1) Earthquake or eruption occurs

2) Nodes detect seismic event

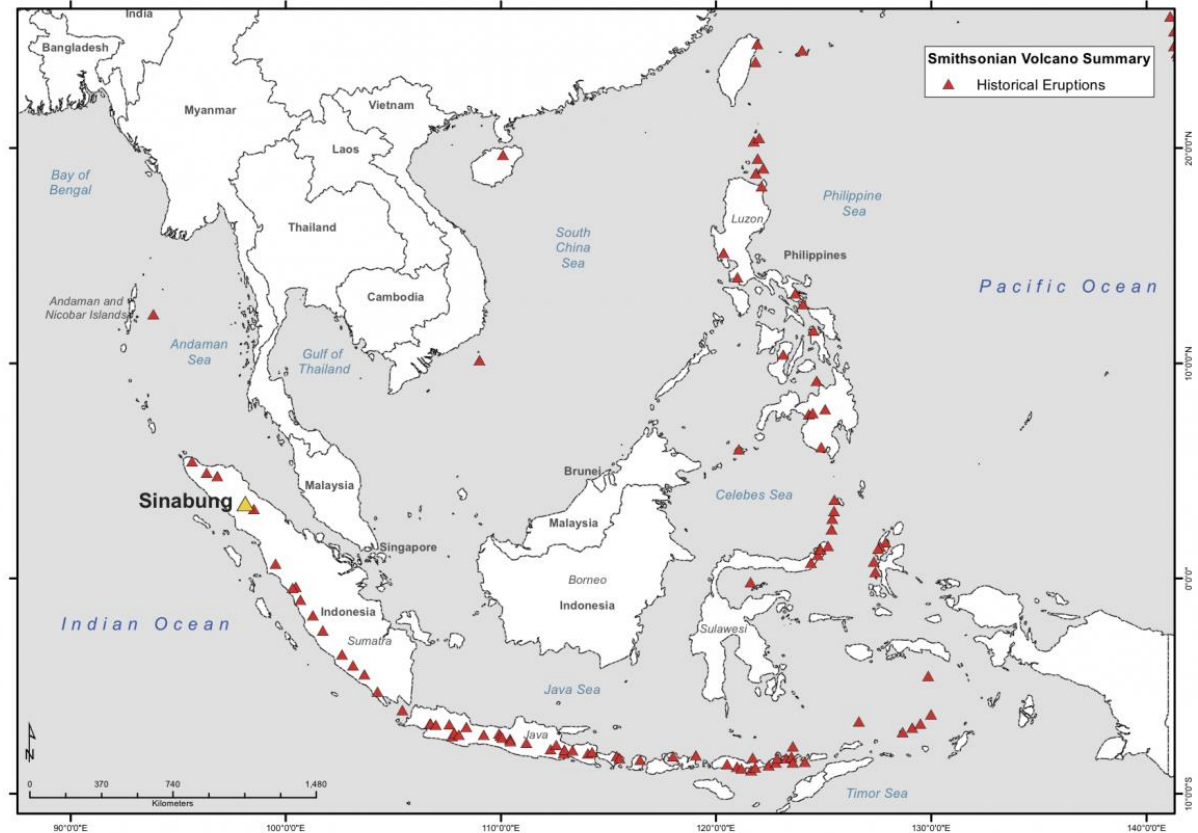
3) Each node sends event report to base station

GPS receiver for time sync

Base station at observatory

Long-distance radio link (4km)

FreeNet radio modem



Example: Volcano Monitoring

- Volcanic earthquake timing using wireless sensor networks

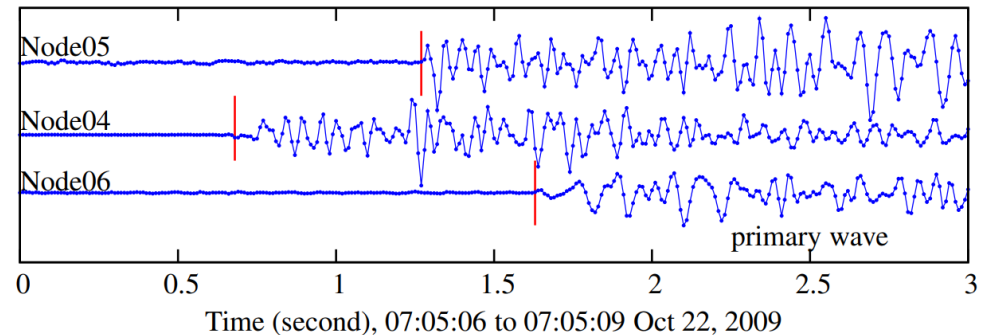


Figure 1: The seismic signals received by three sensors when an earthquake happens on Mount St. Helens. The vertical lines represent the P-phases.

Details: <https://personal.ntu.edu.sg/tanrui/pub/timing-ipsn.pdf>