Smart Objects

Giuseppe Anastasi

Executive Director, Industry 4.0 CrossLab

Dept. of Information Engineering, University of Pisa

E-mail: giuseppe.anastasi@unipi.it

Website: www.iet.unipi.it/g.anastasi/

UNIVERSITÀ DI PISA

DEPARTMENT OF INFORMATION ENGINEERING

CROSSLAB
Innovation for industry 4.0

Smart Object

Real-world object + instrumenting device

Instrumenting devices

- Sensors
  - Passive Sensors
  - Semi-passive Sensors
- Sensor Nodes
  - Sensor Platforms
- Sensor/Actuator Nodes

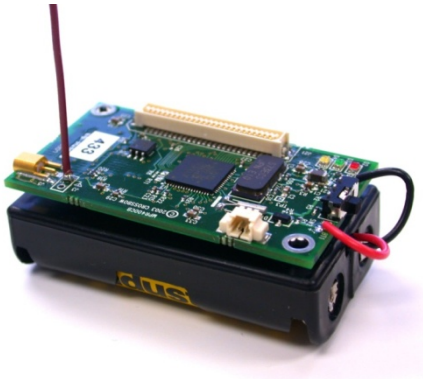
Sensors

Sensors: Classification

- Passive Sensors
  - RFID

- Semi-passive Sensors
  - Data loggers

- Active Sensors
  - Sensor nodes
  - Beacons



CROSSLAB
Innovation for Industry 4.0

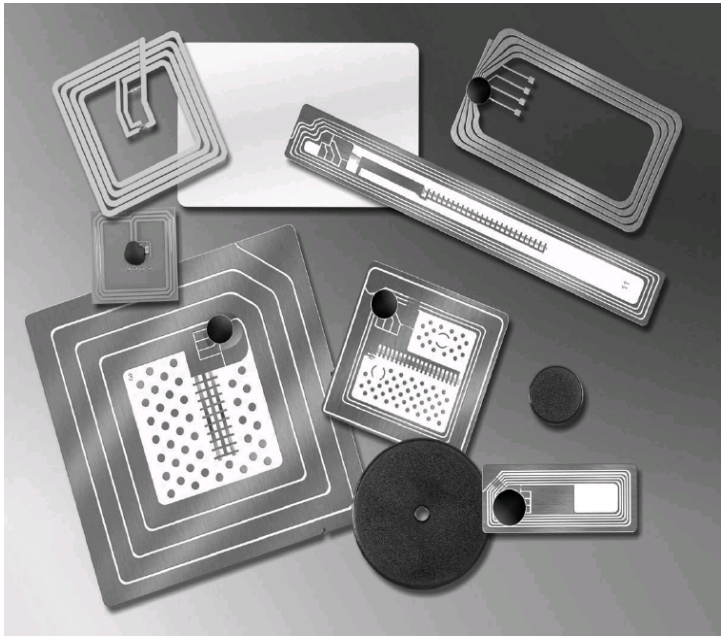
Sensors: Classification

- Temperature
- Humidity
- Light intensity
- Infrared (Presence)
- Sound (Noise)
- Accelerometer
- Compass (direction)
- Speed
- Pressure
- Seismic
- Chemical Sensors
- Optical Sensors
- Pollution
  - CO, CO_2 , NO_2 , O_3, Benzene
  - PM10, PM2.5, PM1
- Smart Meters
  - Power Consumption
  - Energy Consumption
  - Gas Consumption
  - Water Consumption
- …

CROSSLAB
Innovation for Industry 4.0

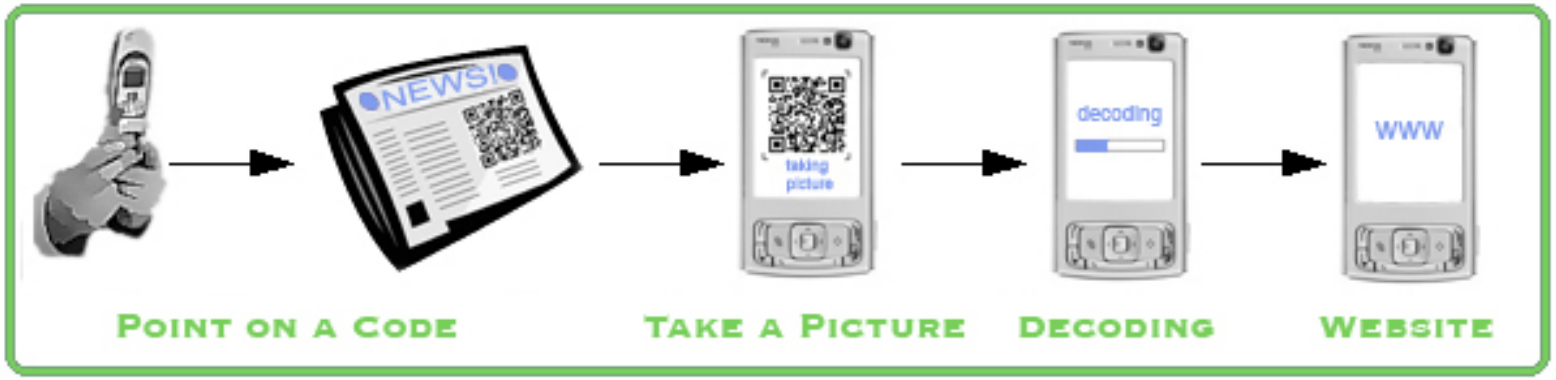
Passive Tags

RFID, QR-codes



Quick Response (QR) Code

Two dimensional barcode that stores information in black and white dots (data pixels or “QR code modules”)



QR code generation

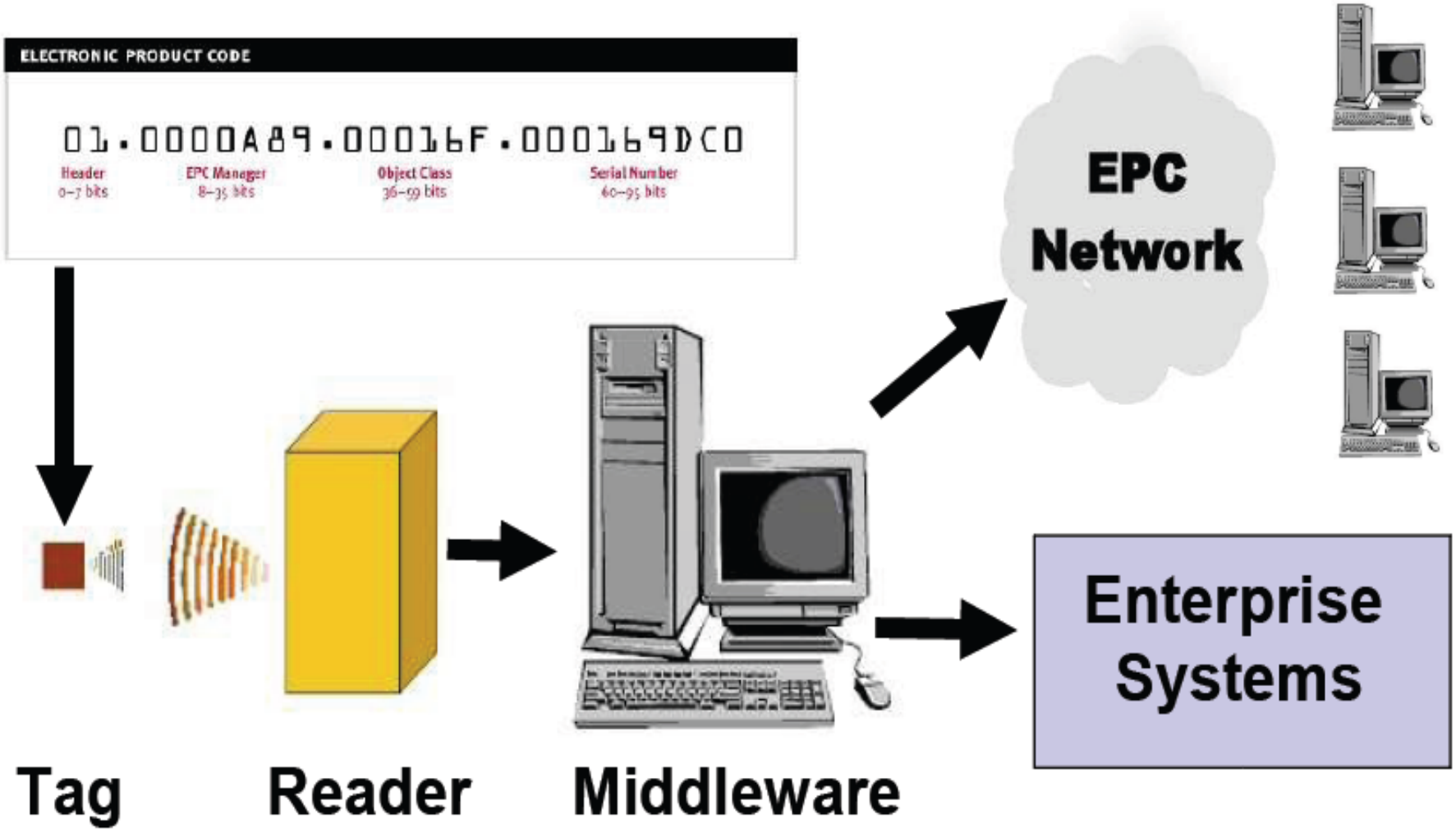
Many online generators available

e.g., http://goqr.me/

- ⇨ URL (Website)
- ⇨ Text
- ⇨ Vcard
- ⇨ Sms
- ⇨ Phone Call
- ⇨ Geolocation
- ⇨ Event
- ⇨ E-mail
- ⇨ WiFi

https://www.dii.unipi.it/

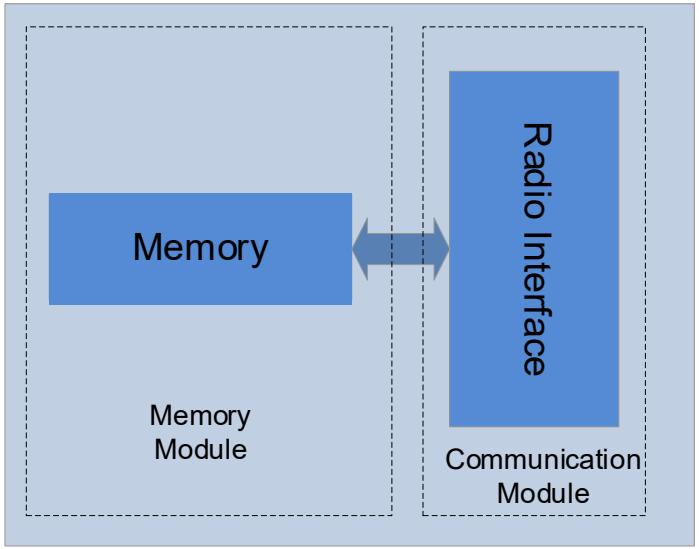
Using RFID


ELECTRONIC PRODUCT CODE
01.0000A89.00016F.000169DC0
Header
0–7 bits
EPC Manager
8–35 bits
Object Class
36–59 bits
Serial Number
60–95 bits
EPC Network
Enterprise Systems
Tag
Reader
Middleware

RFID Architecture

RFID Tags: only connectivity

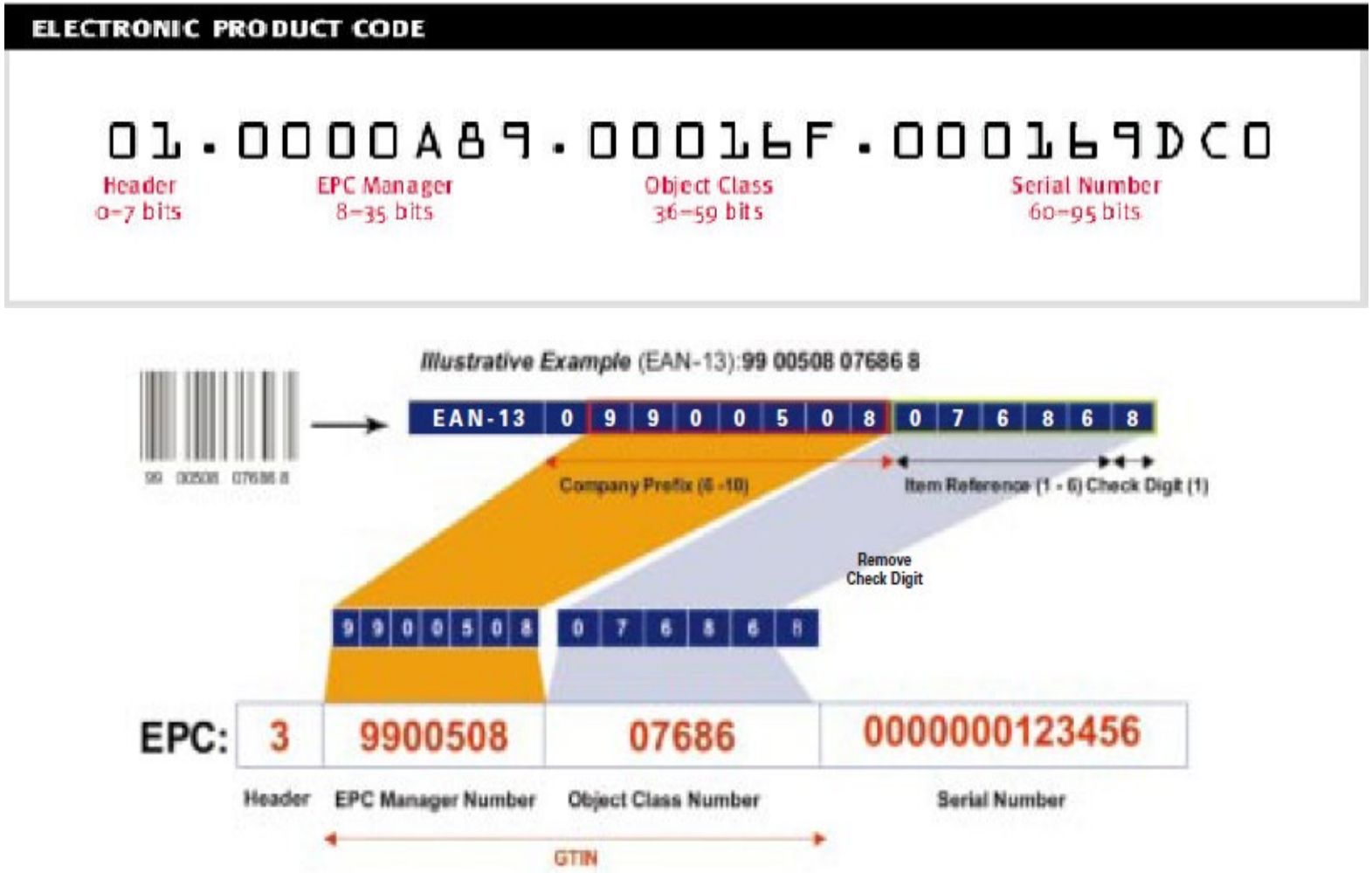
RFID Reader required for communication



Application Areas

- Supply chain management
- Baggage/Animal tagging
- Library information systems
- Parcel tracking (postal services)
- Smart cities
  - Access control
  - Ticketing (public transport, parking, etc.)
  - Parking area management
  - Augmented reality
  - …

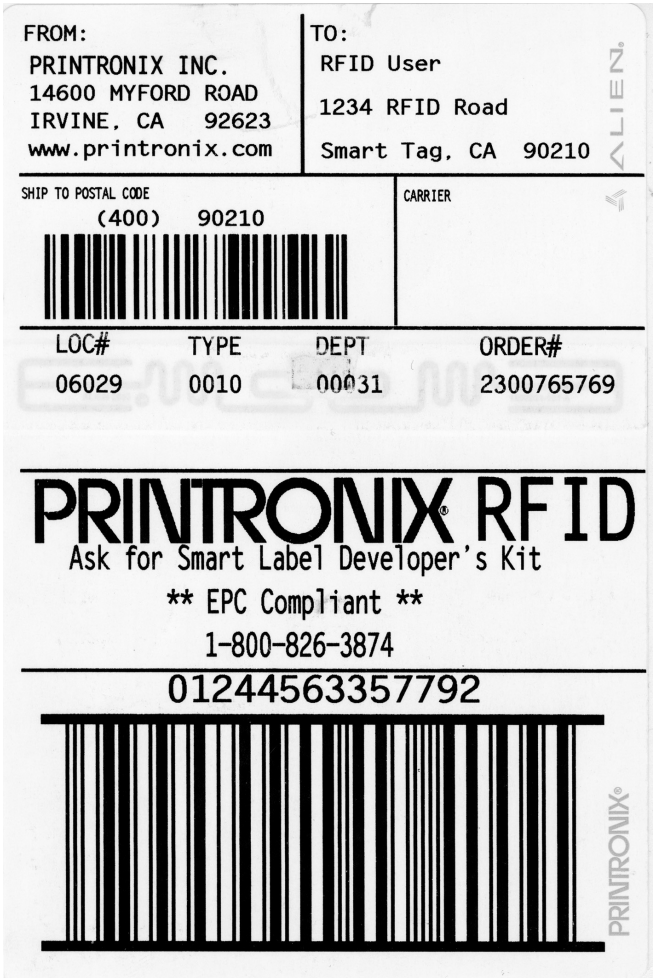
Electronic Product Code



Supply Chair Management

CROSSLAB
Innovation for Industry 4.0

Baggage Tagging

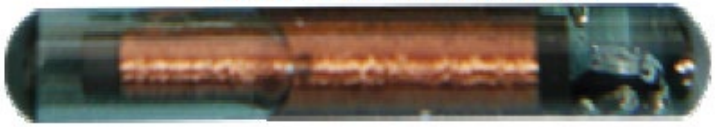


Animal Tagging

TX1400 B 12mm x 2.0mm

TX1410 B 18mm x 3.0mm

TX1415 B 23 mm x 3.83mm

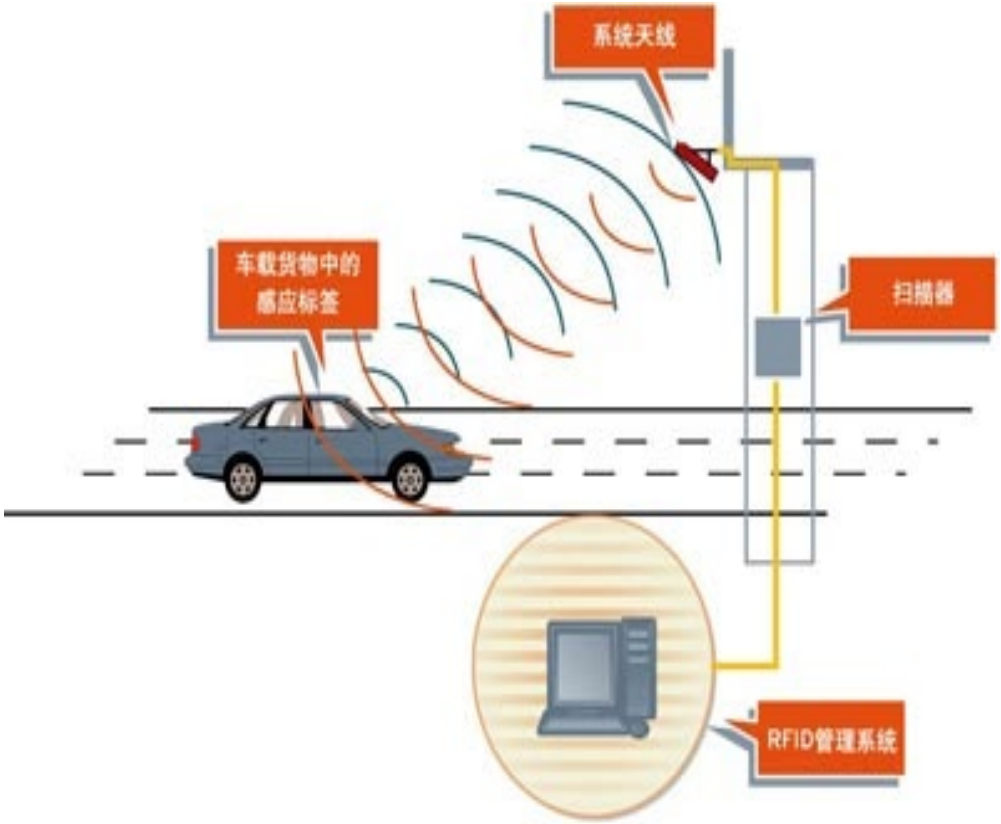


190-0003-00B Rumen Bolus 65mm x 21.1mm

189-0000-00 Umbilical Implant 65mm x 9.8mm

CROSSLAB
Innovation for Industry 4.0

Automatic Access/Tolling



Augmented Reality

Points of interest in the city (touristic point of interest, shops and public places) can be tagged through RFIDs or QR codes

Information about the tagged point are made available to the user (tourist, citizen, …)

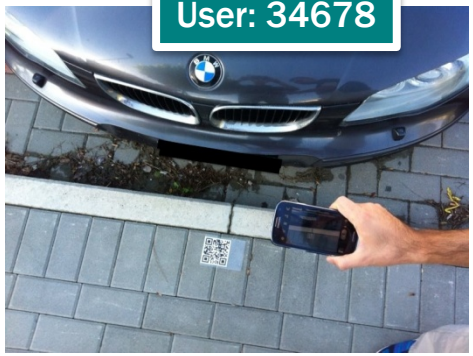
Parking Area Management

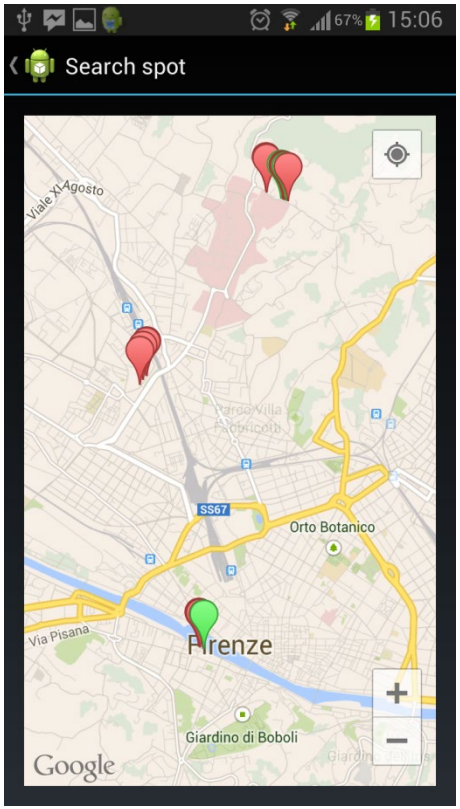
Price
Euro: 2.10
Thanks

After more or less two hours.....

Lot: 12987
Time: 13:15
User: 34678

Lot: 12987
Time: 15:25
User: 34678





CROSSLAB
Innovation for Industry 4.0

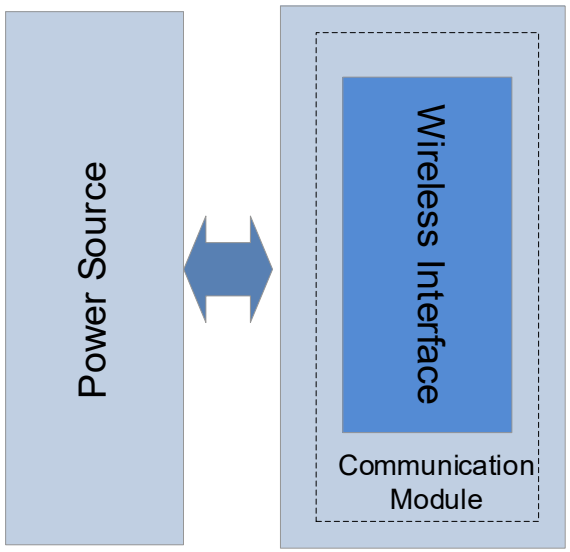
Active Tags

Beacons

Introduction

- iBeacon is a technology originally developed by **Apple**
  - iBeacon-compatible hardware transmitters - typically called Beacons - available also for non-Apple devices
- Enables devices to perform actions when in close proximity to a Beacon
  - Beacons emit periodic signals
  - Mobile devices **understand their location**
    - ⇨ based on the received signal
  - and perform a specific action

Beacon Architecture



Basic Idea

Beacon uses **Bluetooth Low Energy (BLE)** to transmit **Advertisement (ADV) messages**

The ADV message is received by a smartphone and forwarded to a server (e.g., on the cloud)

The server localizes the device (user) and sends appropriate information to the smartphone

Bluetooth Low Energy (BLE)

- Wireless **PAN technology** for novel applications
  - healthcare, fitness, security, home entertainment, …
  - Also known as Bluetooth smart
- **Main goal**
  - providing considerably reduced power consumption and cost
  - while maintaining a similar communication range
- Requirements
  - Android 4.3 and above
  - iOs 7 and above

BLE vs. Traditional Bluetooth

- **Power Consumption**
  - BLE has lower power consumption that traditional Bluetooth
  - Lifetime up to 3 years with a single coin cell battery
- **Cost**
  - BLE is 60-80% cheaper than traditional Bluetooth
- **Applications**
  - BLE is ideal for simple applications requiring periodic transfers of small data
  - Traditional Bluetooth is better for more complex applications
    - ⇨ requiring consistent communication and higher throughput

How BLE works

- BLE communication mainly consists in **Advertisement (ADV) messages**
  - small data packets broadcast at a regular interval by enabled devices via radio waves
  - **one-way** communication

- Typical parameter values for Beacons
  - Broadcast interval of 100 ms
  - Broadcast range of up to 100 meters

Beacon Advertisement Messages

Advertisement messages consist of four main pieces of information

- UUID (Universal Unique IDentifier)
- Major
- Minor
- Tx Power

Beacon Advertisement Message

- UUID (Universal Unique IDentifier)
  - 16 byte string used to differentiate a large group of related Beacons
  - In its canonical form, a UUID is represented by 32 lowercase hexadecimal digits, displayed in five groups separated by hyphens, in the form 8-4-4-4-12 for a total of 36 characters
  - E.g., ebefd083-70a2-47c8-9837-e7b5634df524
- Major
  - 2-byte string distinguishing a subset of Beacons within the larger group
- Minor
  - 2-byte string used to identify individual Beacons
- Tx Power
  - Used to determine proximity (distance) from the beacon
    - ⇨ TX power is defined as the strength of the signal at exactly 1 meter from the device.
    - ⇨ This has to be calibrated and hardcoded in advance. Devices can then use this as a baseline to give a rough distance estimate.

Example

Application for locating people within the University of Pisa

- UUID (Universal Unique IDentifier)
  - ⇨ Allows to recognize that ADV messages are emitted from Beacons belonging to the University of Pisa
- Major
  - ⇨ Identifies ADV messages emitted from Beacons inside a specific building belonging to the University of Pisa (e.g., Building A)
- Minor
  - ⇨ Identifies a specific room in that Building (e.g., Room A28)

Example

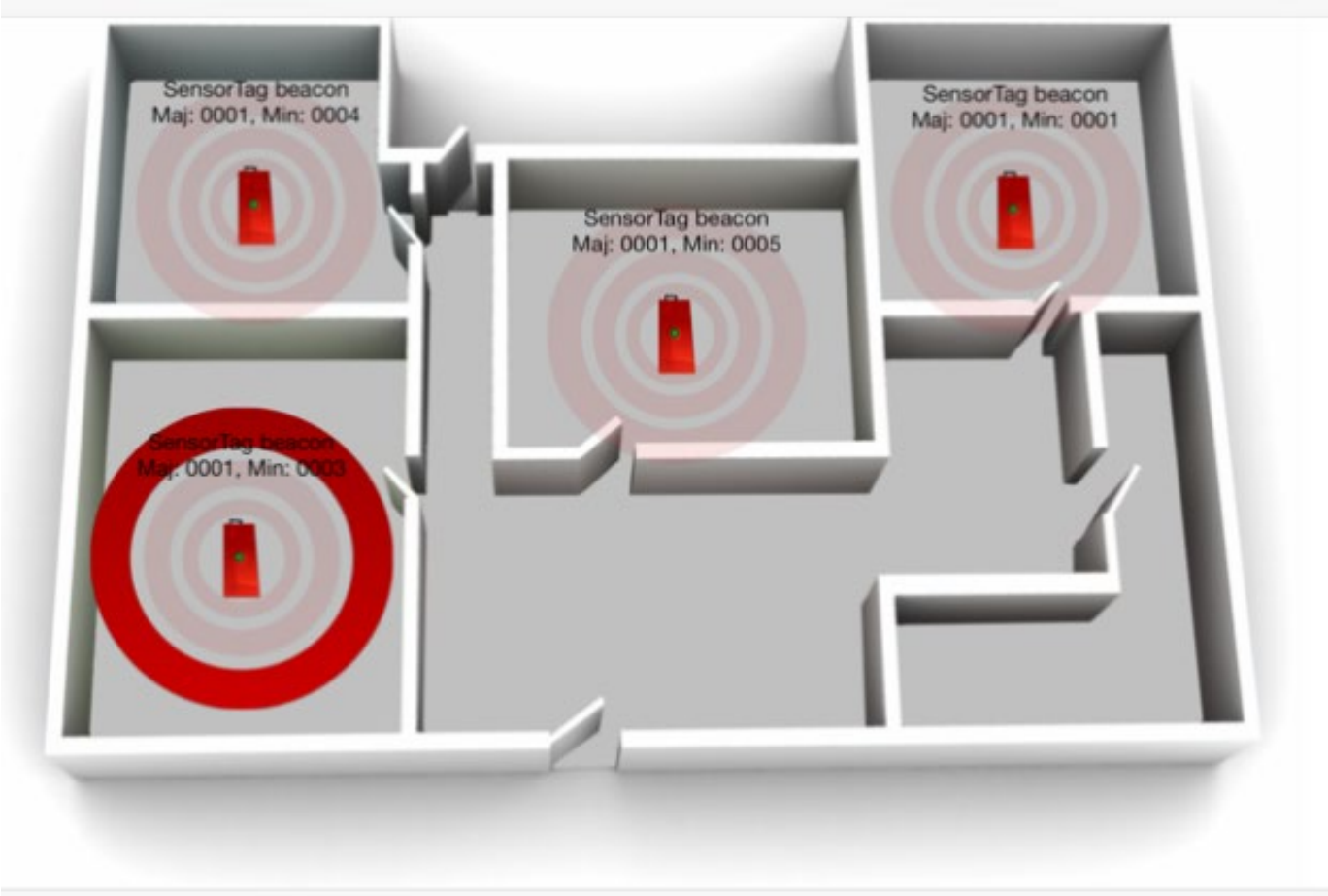
A beacon broadcasts the following ADV message

- UUID: ebefd083-70a2-47c8-9837-e7b5634df524
- Major: 21
- Minor: 17

The system realizes that it was emitted by a Beacon located at the **University of Pisa** (UUID), in **Building A** (Major), inside the **Room A28**(Minor)

Application Areas

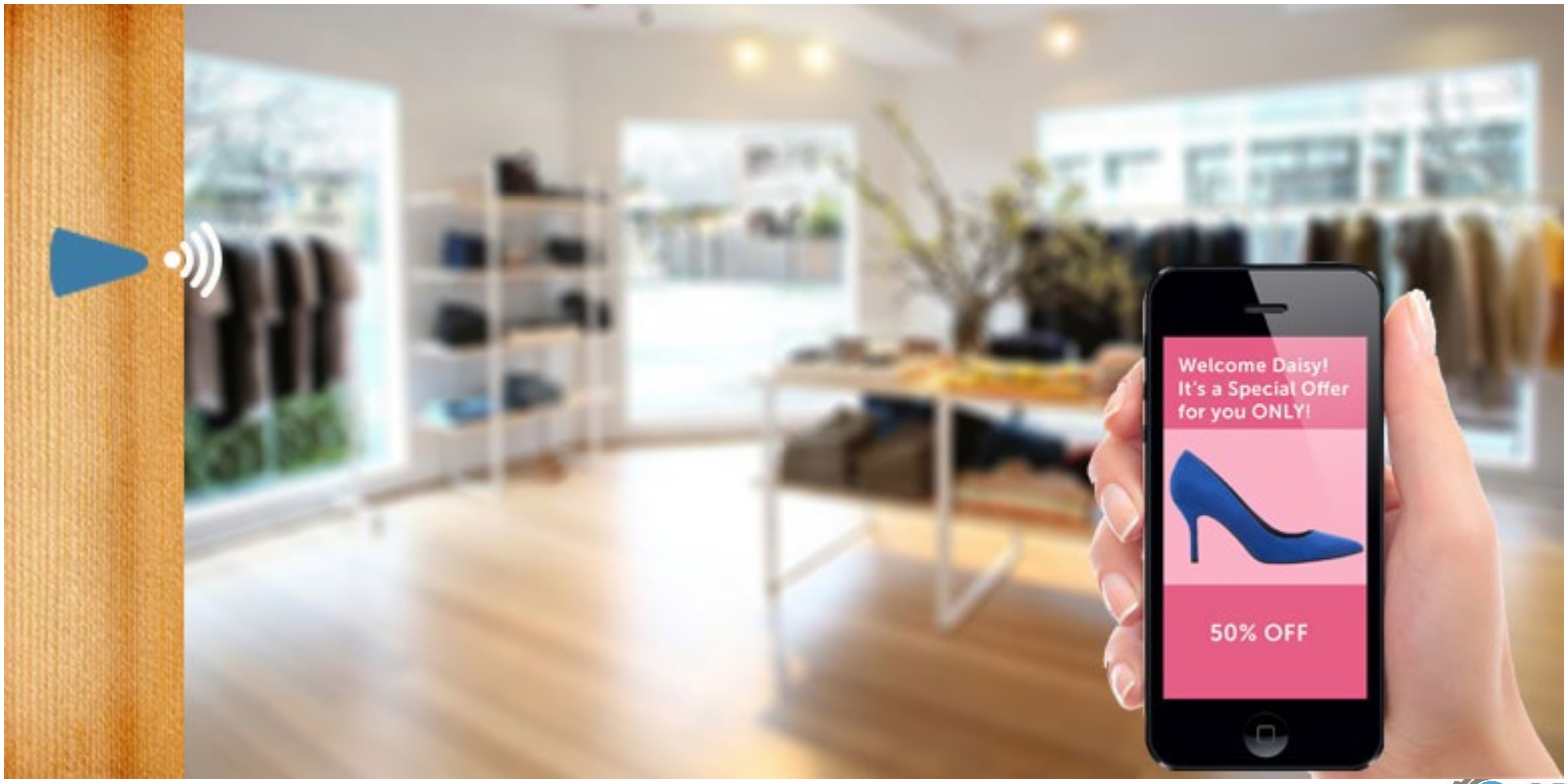
Localization in Buildings



CROSSLAB
Innovation for Industry 4.0

Application Areas

Retails: coupons delivered via Beacons to customer phone (e.g., special offers)

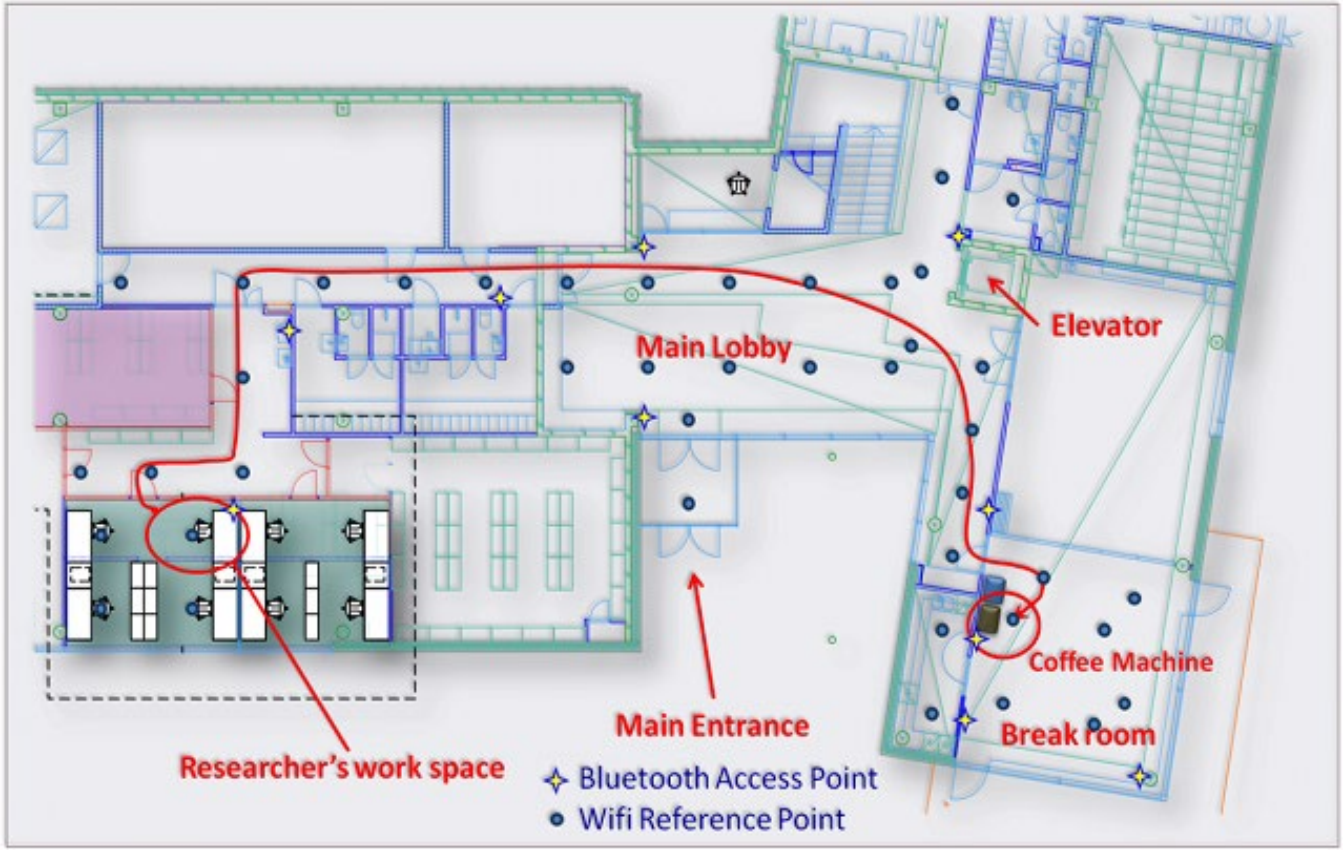


Application Areas

Tracking: locate museum artworks, shop products, or cargo containers

Applications Areas

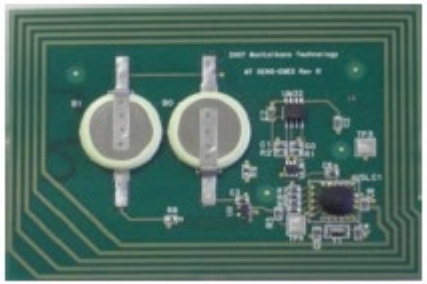
Indoor Navigation: path discover inside a building and user localization



Application Areas

Smart Tagging: allows to give more information about artworks (also in many languages)

Semi-Passive Sensors

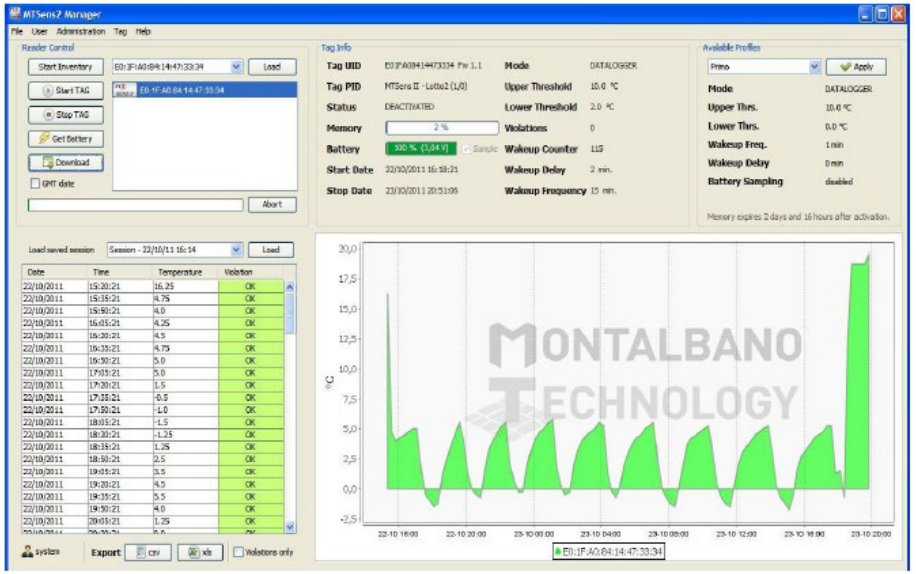


Semi Passive Sensors

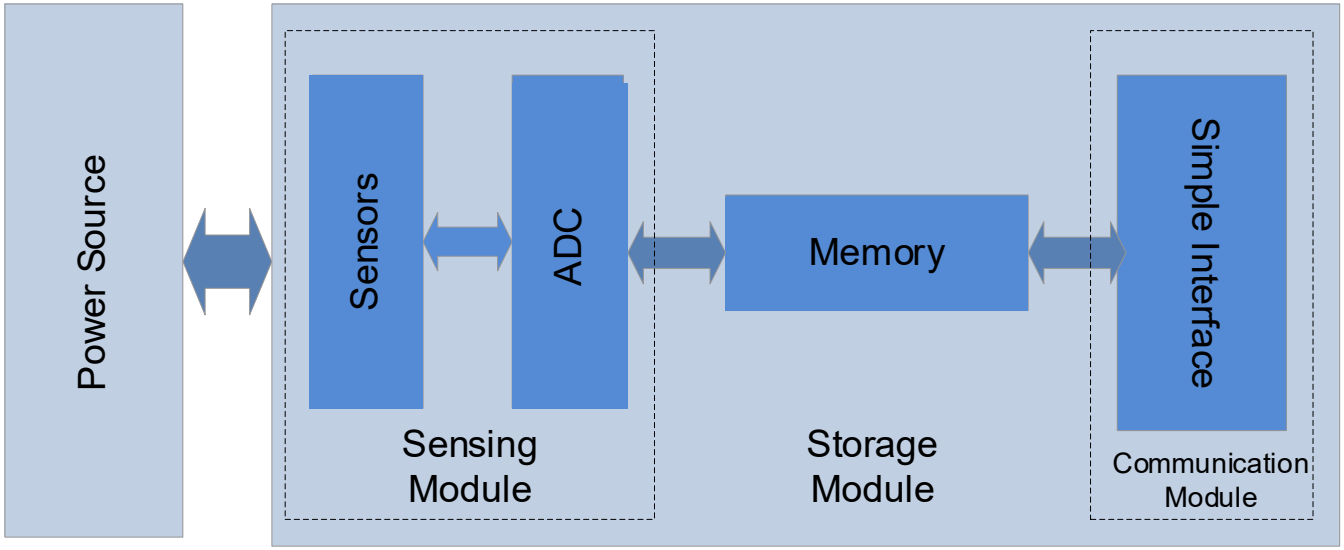
- Also called data loggers
- Powered by a battery
- Measures and stores physical quantities
  - Temperature
  - Humidity
  - Shock
  - …
- Can be attached to goods to track their history
  - Low-cost solution

System Architecture

- Semi-passive Tag
- Reader
- Server
- Data manager
  - Tag management
  - Data retrieval and archival
  - Data visualization
    - ⇨ Table, plots



Device Architecture



MTSensell Data Logger

RFID	ISO15693 (13,56 MHz)
Modalità di Acquisizione	1.Modalità senza soglie (datalogger): il tag acquisisce la temperatura ad intervalli regolari (impostabili dall'utente) 2.Solo violazioni di temperatura: vengono memorizzate solamente le temperature che si trovano al di fuori delle soglie di temperatura impostate 3.Registrazione continua con indicazione del numero di violazioni: il funzionamento è identico a quello senza soglie con la differenza che viene comunque tenuta traccia del numero delle temperature fuori soglia (violazioni).
Temperatura Operativa	-30°C; +60°C
Risoluzione	0,25°C
Accuratezza	±1°C
Capacità di memoria (2)	3840 nella prima e terza modalità di acquisizione 1920 nella seconda modalità (solo violazioni di temperatura)
Tempo di campionamento temperatura	L'intervallo dei valori per il tempo di campionamento è compreso tra 1 minuto e 1440 minuti (24 ore).
Programmazione Delay	Valore intero espresso in minuti che indica dopo quanto tempo il tag dovrà partire rispetto all'attivazione del tag.
Area dati utente	26 byte x 32 (832 Byte) a disposizione per la memorizzazione di dati personali.
Dimensioni	89mm x 69mm x 4.5mm
Durata Batterie (funzionamento continuo a +25°C)	10 mesi (2)
Lettura diretta del valore della batteria	(3)

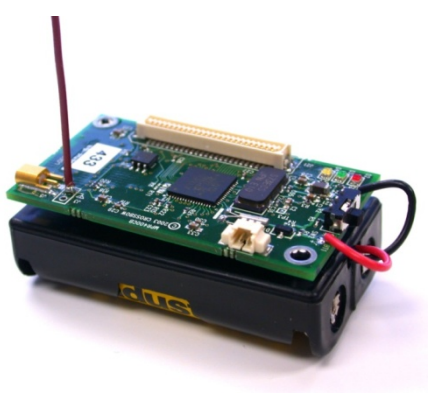
Application Areas

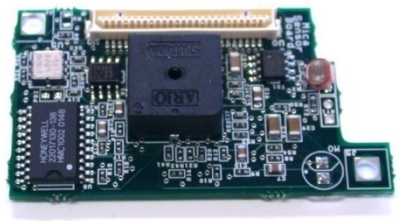
- Ice cream, Frozen Products Distribution
  - Temperature monitoring
- Wine Transport
  - Temperature monitoring
  - Shock tracking
- Blood Bags Transport
  - Bag Identification
  - Temperature tracking
- …

Home work

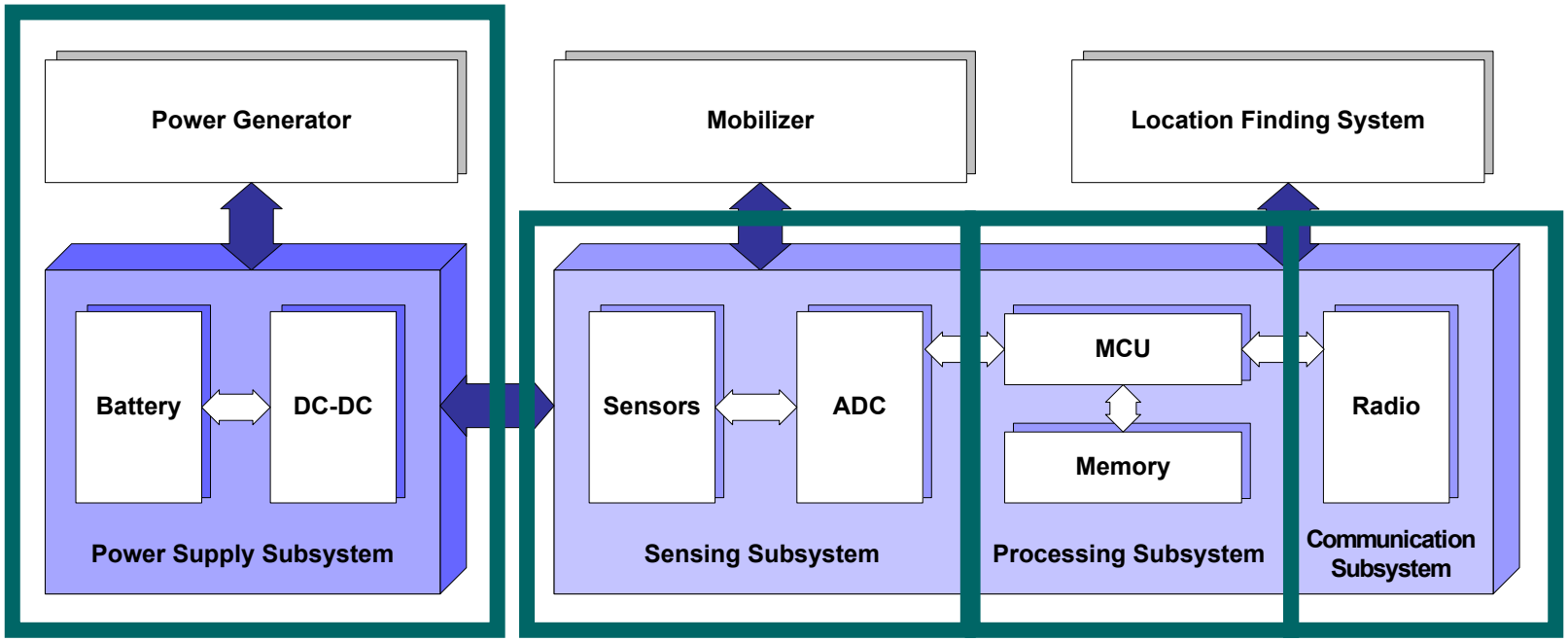
- Form small groups
- Think about possible simple application based on Passive/active tags
  - ⇨ Objectives
  - ⇨ Requirements
  - ⇨ Main components
  - ⇨ Links between components

Sensor Nodes





Sensor Node Architecture



Battery powered devices

Batteries cannot be changed or recharged

Usually negligible power consumption

Short range wireless communication

Radio is the most power consuming component

Available Sensor Platforms

Sensor Node	Microcontroller	Transceiver	Program+Data Memory	External Memory	Programming	Remarks
BT node	Atmel ATmega 128L (8 MHz @ 8 MIPS)	Chipcon CC1000 (433-915 MHz) and Bluetooth (2.4 GHz)	64+180 K RAM	128 KB FLASH ROM, 4 KB EEPROM	C and nesC Programming	BTnut and TinyOS support
IMote	ARM core 12 MHz	Bluetooth with the range of 30 m	64 KB SRAM	512 KB flash		TinyOS Support
IMote 1.0	ARM 7TDMI 12-48 MHz	Bluetooth with the range of 30 m	64 KB SRAM	512 KB flash		TinyOS Support
IMote 2.0	Marvell PXA271 ARM 11-400 MHz	TI CC2420 802.15.4/ZigBee compliant radio	32 MB SRAM	32 MB flash		Microsoft .NET Micro, Linux, TinyOS Support
Mica	ATmega 103 4 MHz 8-bit CPU	RFM TR1000 radio 50 kbit/s	128+4 KB RAM	512 KB flash	nesC Programming	TinyOS Support
Mica2	ATMEGA 128L	Chipcon 868/916 MHz	4 KB RAM	128 KB flash		TinyOS, SOS and MantisOS Support
Mica2Dot	ATMEGA 128		4 KB RAM	128 KB flash		
MicaZ	ATMEGA 128	TI CC2420 802.15.4/ZigBee compliant radio	4 KB RAM	128 KB flash	nesC	TinyOS, SOS, MantisOS and Nano-RK Support
TelosB	Texas Instruments MSP430 microcontroller	250 kbit/s 2.4 GHz IEEE 802.15.4 Chipcon Wireless Transceiver	10 KB RAM	48 KB flash		Contiki, TinyOS, SOS and MantisOS Support
T-Mote Sky	Texas Instruments MSP430 microcontroller	250 kbit/s 2.4 GHz IEEE 802.15.4 Chipcon Wireless Transceiver	10 KB RAM	48 KB flash		Contiki, TinyOS, SOS and MantisOS Support

http://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes

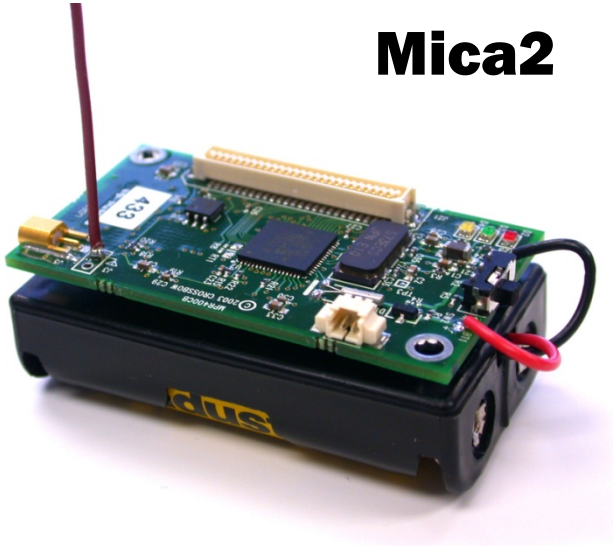
Available Sensor Platforms

Sensor Node	Microcontroller	Transceiver	Program+Data Memory	External Memory	Programming	Remarks
Waspmote	Atmel ATmega 1281	ZigBee/802.15.4/DigiMesh/RF, 2.4 GHz/868/900 MHz	8 KB SRAM	128 KB FLASH ROM, 4 KB EEPROM, 2 GB SD card	C/Processing	GPRS, Bluetooth, GPS modules, sensor boards..
Zolertia Z1	Texas Instruments MSP430F2617	Chipcon CC2420 2.4 GHz IEEE 802.15.4 Wireless Transceiver	8 KB RAM	92 KB flash	C, nesC	Contiki and TinyOS Support. 16 Mbit external flash + 2 digital on-board sensors
WiSense	TI MSP430G2955	TI CC2520 (2.4 GHz), TI CC1101 (865-867 MHz)	4 KB RAM	56 KB FLASH, 256 bytes EEPROM	C	Modular (pluggable), No OS (Loop with event flags), Basic node includes temperature sensor, light sensor and coin cell retainer
Shimmer	MSP430F1611	802.15.4 Shimmer SR7 (TI CC2420)	48 KB flash 10 KB RAM	2 GB microSD Card	nes C and C Programming	TinyOS Support. Built in 3 Axis Accel, Tilt/Vib Sensor. Full range of expansion modules.
SunSPOT	ARM 920T	802.15.4	512 KB RAM	4 MB flash	Java	Squawk Java ME Virtual Machine
....						

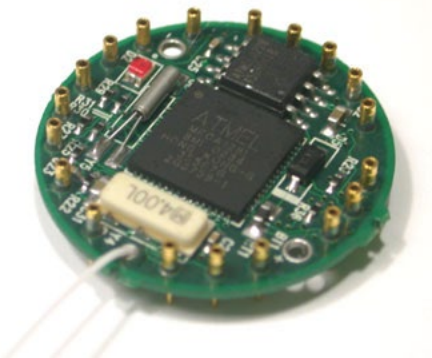
http://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes

Mica Motes

Mica2

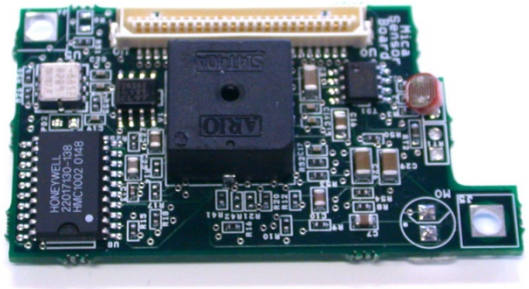


Mica2dot

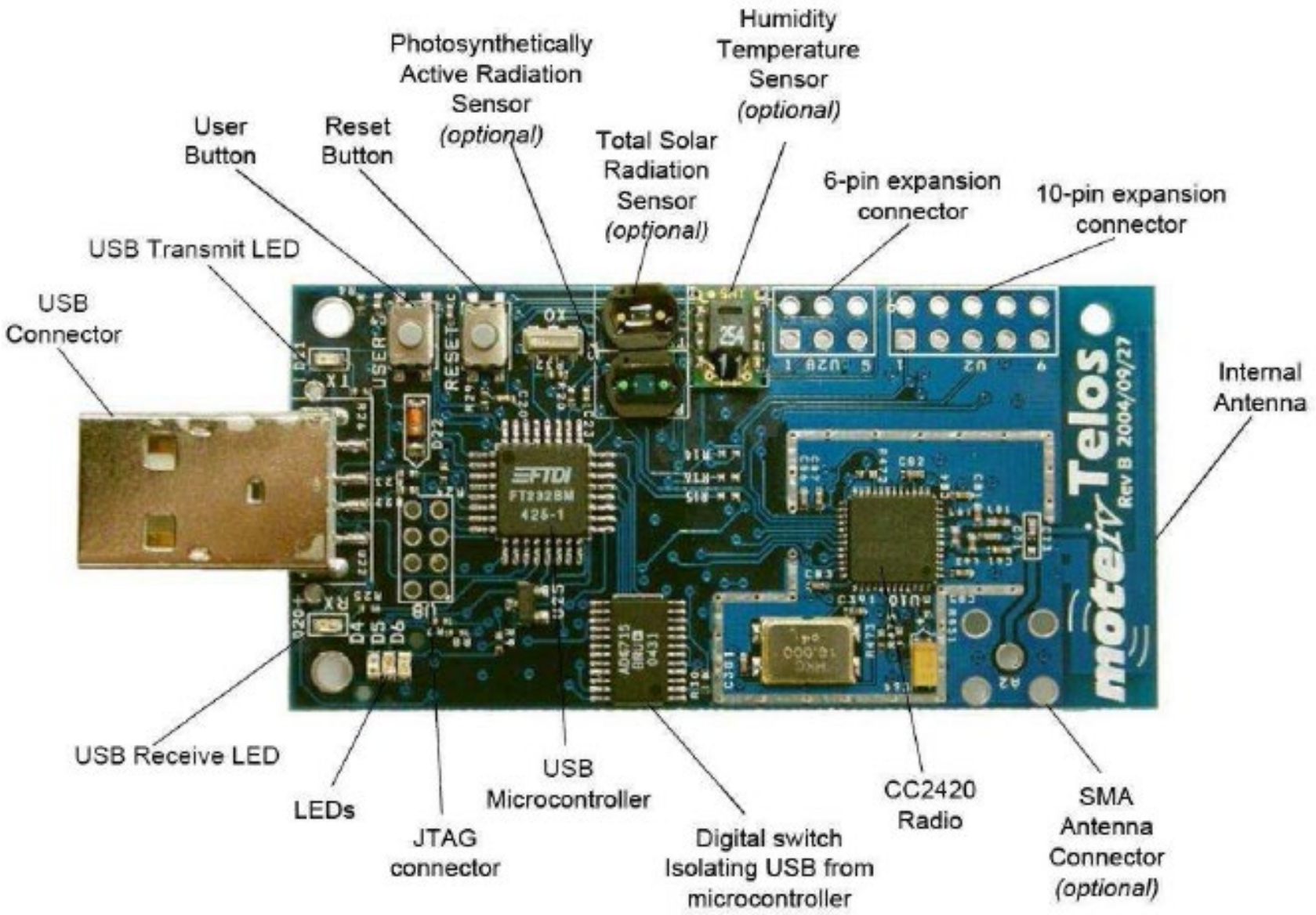


Sensor Board for Mica

light, temperature, accelerometer, magnetometer, microphone, tone detector, 4.5 Khz sounder



Telos/Tmote Sky Mote



Challenges to be addressed

- Driven by interaction with environment
  - Message arrival, sensor acquisition
  - Concurrency Management
    - ⇨ Event arrival and data processing are concurrent activities
    - ⇨ Potential bugs must be managed (e.g., race conditions)
- Limited Resource
  - Due to small size, low cost and low power consumption
- Reliability
  - Although single node may fail, we need long-lived applications
  - No recovery mechanism in field, except automatic reboot
- Soft real-time requirements

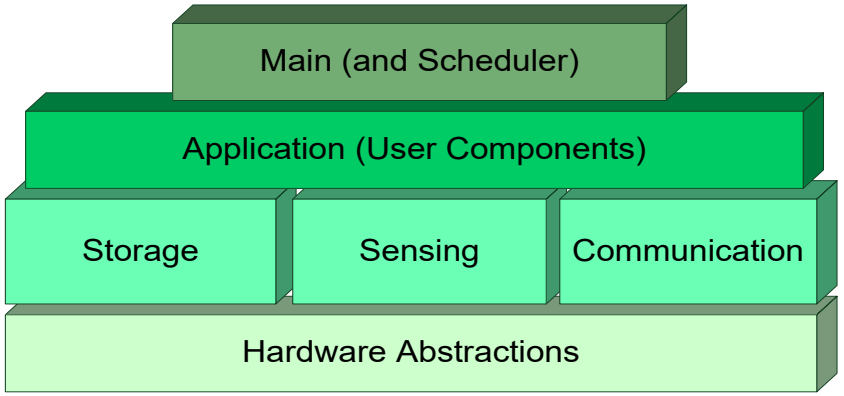
The TinyOS Operating System

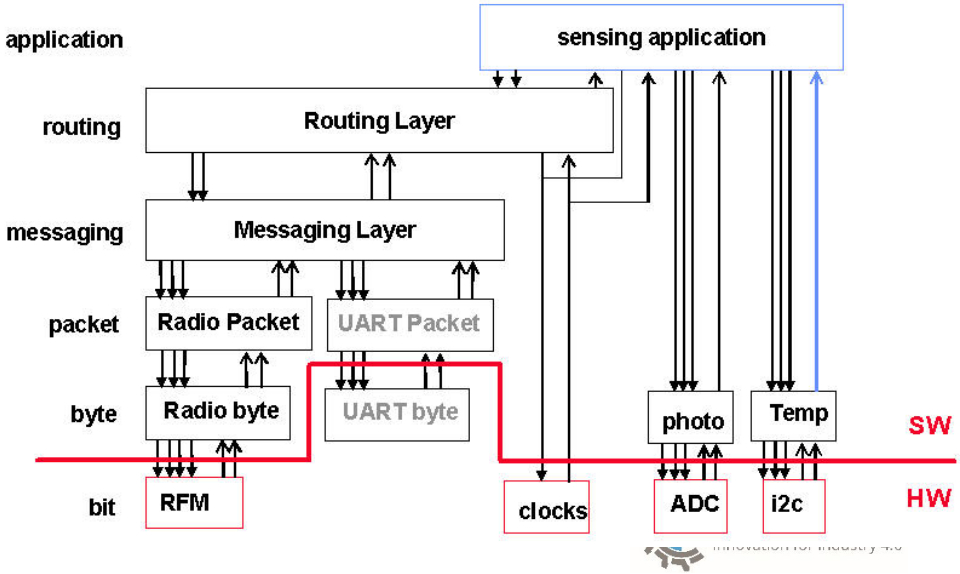
- Specifically targeted to WSNs
  - Component-based architecture
  - Event-based concurrency
  - Split-phase operation

http://www.tinyos.net/

TinyOS Architecture

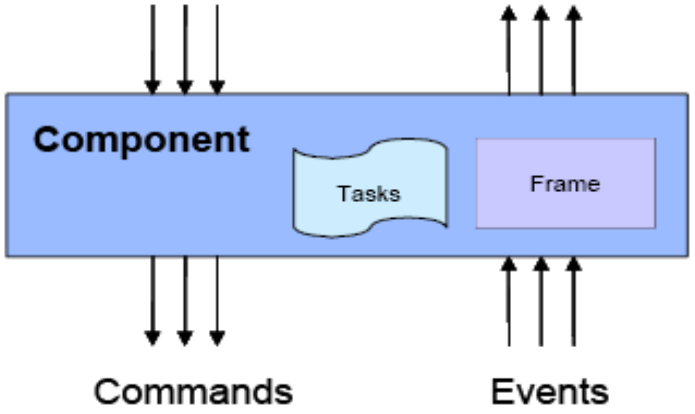
- Component-based architecture
- Components
  - Software modules
  - Hardware modules
  - The distinction is invisible to developers
- Unused Services
  - Excluded from the application





Component-based computation model

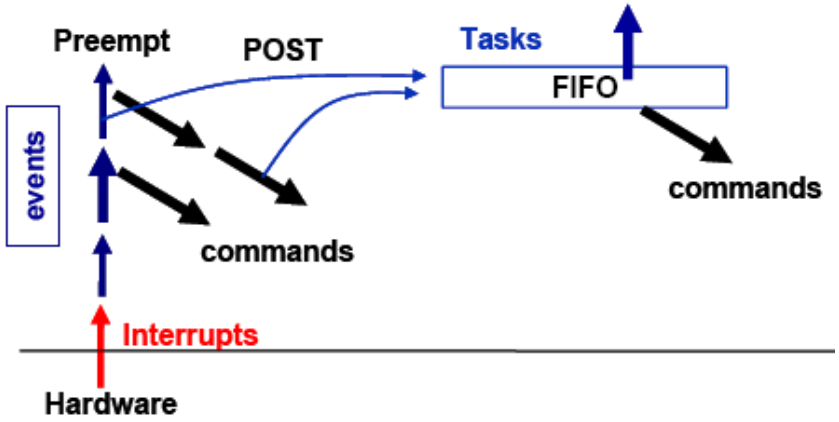
- Component
  - computing entity
    - ⇨ interface (commands and events)
    - ⇨ frame (private variables)



- Computing abstractions
  - command
    - ⇨ service request to a component
    - ⇨ non-blocking
  - event
    - ⇨ command completion, message or interrupt
  - task
    - ⇨ context of execution (~function)
    - ⇨ run to completion, preemption by event

Concurrency Management

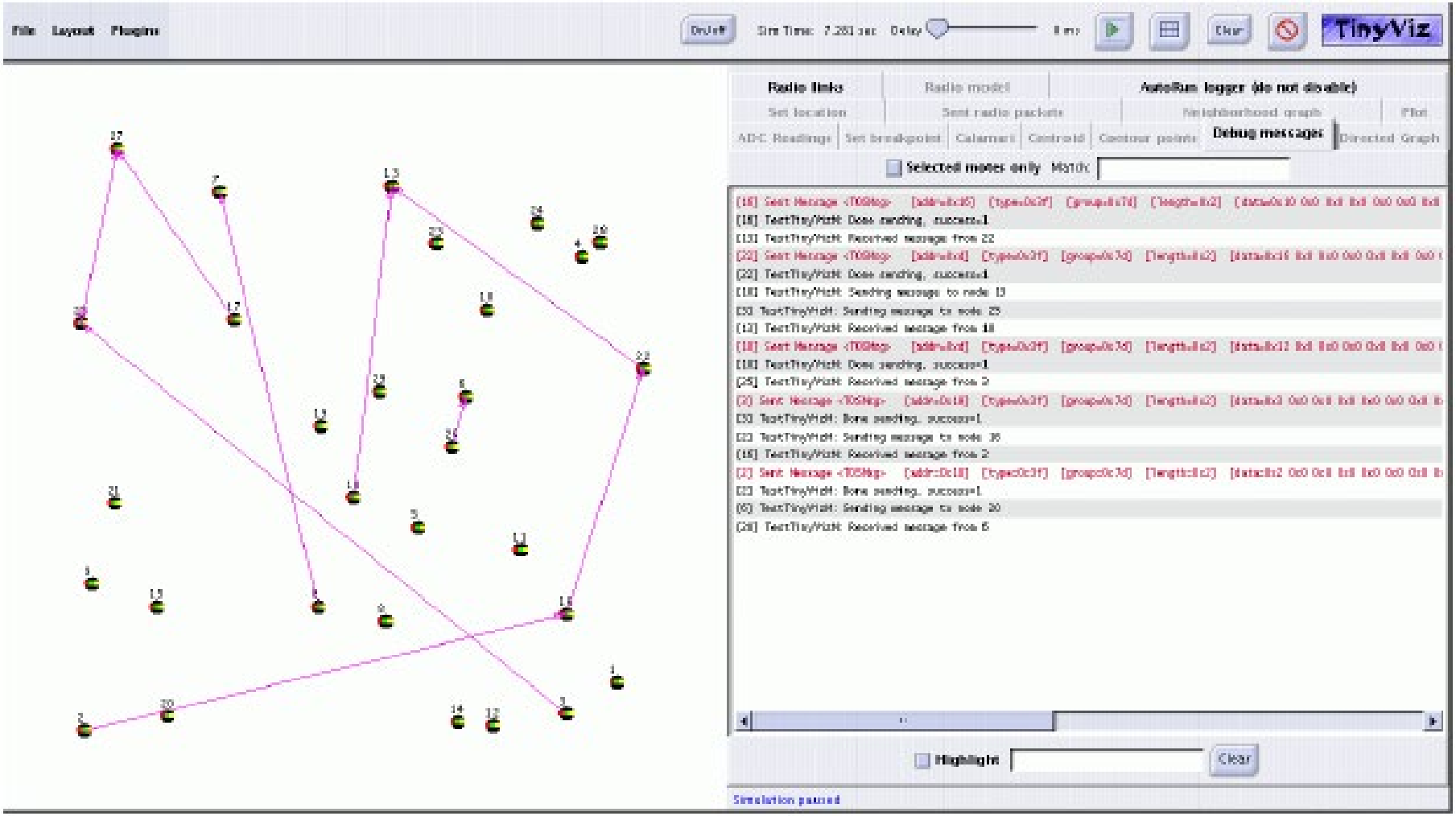
- Two sources of concurrency
  - Tasks and Events (interrupts)
  - Components can post a task
  - The post operation returns immediately
- Task scheduling
  - FIFO (non pre-emptive)
- Tasks run to completion
  - Can be pre-empted only by events
- Events run to completion
  - Signify either an external event (message) or completion of a split-phase operation
  - May pre-empt tasks



TinyOS development environment

- nesC language
  - extension to the C language
  - definition of interfaces
  - abstraction between definition and composition of components
- nesC compiler and OS source
  - composition of the component graph (at compilation time)
  - TinyOS computational model (additional checks)
- TOSSIM simulator
  - same code runs in actual nodes and simulator
  - flexible models for radio and sensors
  - scripting (Tython), graphical interface (TinyViz)

TinyViz


File
Layout
Plugins
Run#
Sim Time: 7.281 sec
Delay
Clear
TinyViz
Radio links
Radio model
AutoRun logger (do not disable)
Set location
Sent radio packets
Neighborhood graph
Plot
ADC Readings
Set breakpoint
Calamari
Centroid
Contour points
Debug messages
Directed Graph
Selected motes only
Match:
Highlight
Clear
Simulation paused

Tutorials on TinyOS Programming Environment

- TinyOS/TOSSIM Tutorial, http://docs.tinyos.net/index.php/TinyOS_Tutorials
- TinyOS Reference Manual, http://www.tinyos.net/tinyos-2.x/doc/pdf/tinyos-programming.pdf
- D. Gay et al., "The nesC Language: A Holistic Approach to Networked Embedded Systems", 2002.
- nesC Reference Manual, http://www.tinyos.net/dist-2.0.0/tinyos-2.0.0beta1/doc/nesc/ref.pdf

Contiki Operating System

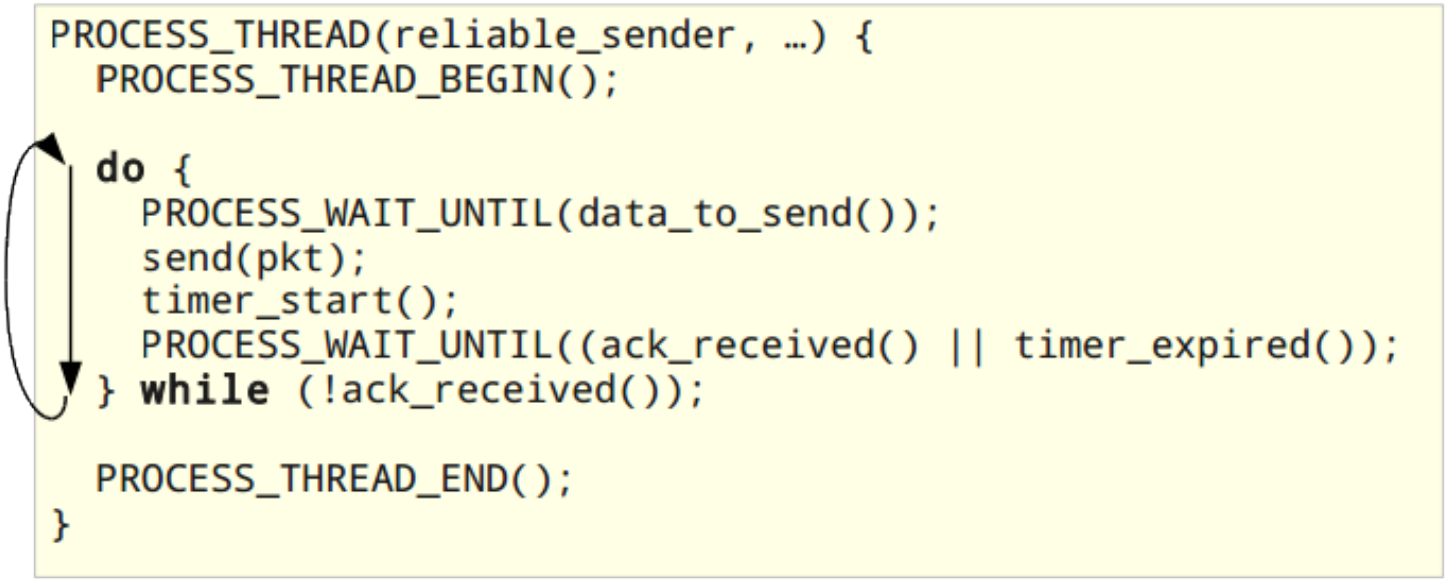
- Limited Memory Footprint
- Event-driven Kernel
- Portability
  - Many different platform supported
    - ⇨ Tmote Sky, Zolertia, RedBee, etc
- C Programming
- Academic and Industrial support
  - Cisco and Atmel are part of the *Contiki project*

Contiki Operating System

- Protothread (optional multi-threading)
- Dynamic Memory Allocation
- TCP/IP stack (uIP)
  - Both IPV4 and IPv6
- Power profiling
- Dynamic loading and over-the-air programming
- IPsec
- On-node database Antelope
- Coffee file system
- …

Contiki Operating System

- Prototread example
  - Stop-and-wait sender



```
PROCESS_THREAD(reliable_sender, …) {
  PROCESS_THREAD_BEGIN();

  do {
    PROCESS_WAIT_UNTIL(data_to_send());
    send(pkt);
    timer_start();
    PROCESS_WAIT_UNTIL((ack_received() || timer_expired());
  } while (!ack_received());

  PROCESS_THREAD_END();
}
```

References

- A. Dunkels, B. Gronvall, T. Voigt, “Contiki - a lightweight and flexible operating system for tiny networked sensors”, IEEE International Conference on Local Computer Networks, 16-18 November 2004
- Contiki: The Open Source OS for the Internet of Things, http://www.contiki-os.org/
  http://en.wikipedia.org/wiki/Contiki
- Contiki, Processes. Available Online at: https://github.com/contiki-os/contiki/wiki/Processes

Mote's Application Areas

- Environmental Monitoring
  - Temperature, Humidity, Light Intensity, …
- Presence Detection
  - Home security systems
  - Energy efficiency in buildings
- Location Detection
  - Anti-theft systems
- Activity Detection
  - Fall detection
  - Athlete monitoring
- …

A very special sensor node

Very Special Sensor Node

Mobile Phone Sensing Applications

- Personal Sensing
  - E.g., personal tracking
  - SoundSense
- E-health
  - Fall detection, Activity detection
  - Well-being support
- CenceMe
  - Captures what the user is doing and the information on their surrounding context (collectively called sensing presence)
  - Pushes collected information to facebook, myspace and twitter
- EyePhone
  - Allows to activates your mobile phone using only your eyes

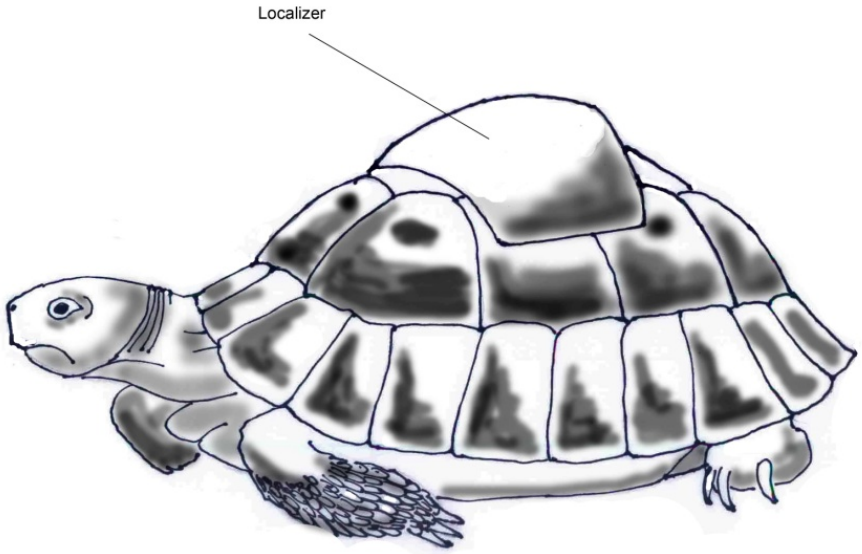
You can find a lot of interesting apps at http://sensorlab.cs.dartmouth.edu/index.html

Participatory Sensing

Citizens utilize their mobile phones to send physical sensing information to a data collection center

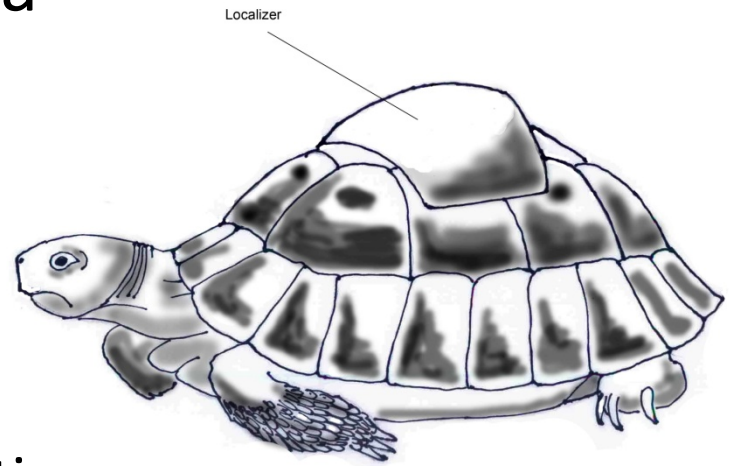
Sensing information can be used for various applications

An example of smart object (animal)



Tortoise@

- Project of the University of Pisa
  - Dept. of Computer Science
  - Dept. of Information Engineering
  - Patent Pending



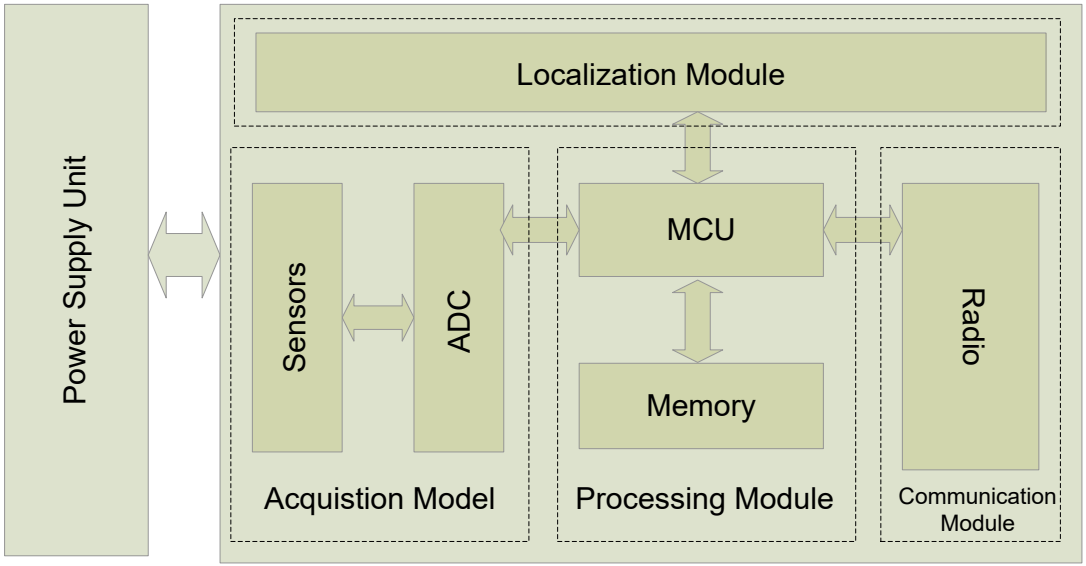
- Goal
  - protection of wild tortoise populations
  - early localization of the nesting sites
- Solution
  - sensor-based system installed on top of the carapace
  - localizes the tortoise during its deposition phase
  - transmits its geographic coordinates to a remote control center in real time

CROSSLAB
Innovation for Industry 4.0

Tortoise@: challenges

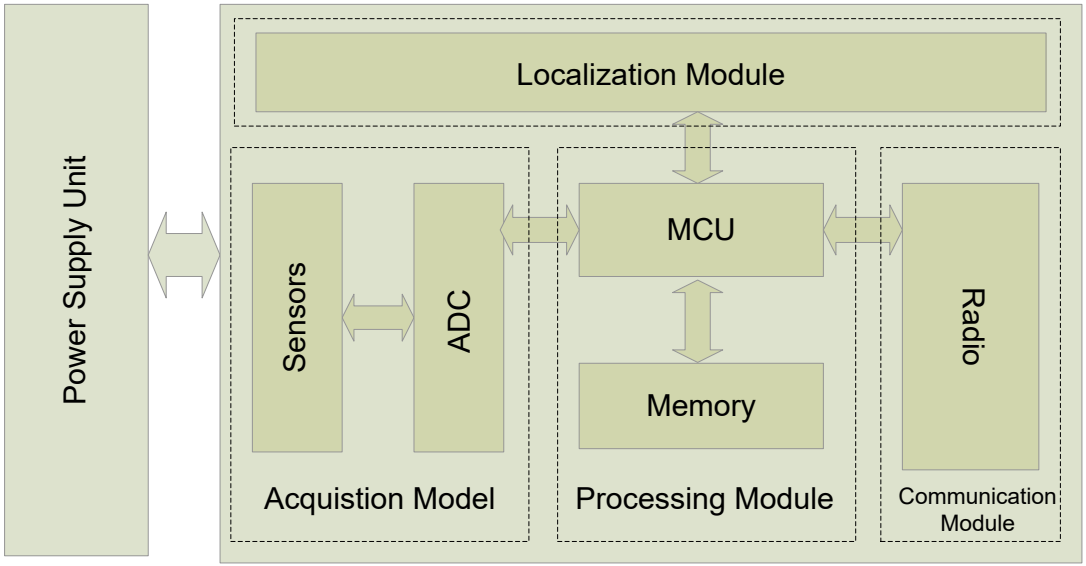
- Weight limitations
- Form factor
- Energy limitations
  - Power management strategies
- Deposition pattern recognition
  - Deposition occurs only under some environmental conditions
  - Typical movements
    - ⇨ Due to nest excavation phase

Tortoise@: system architecture



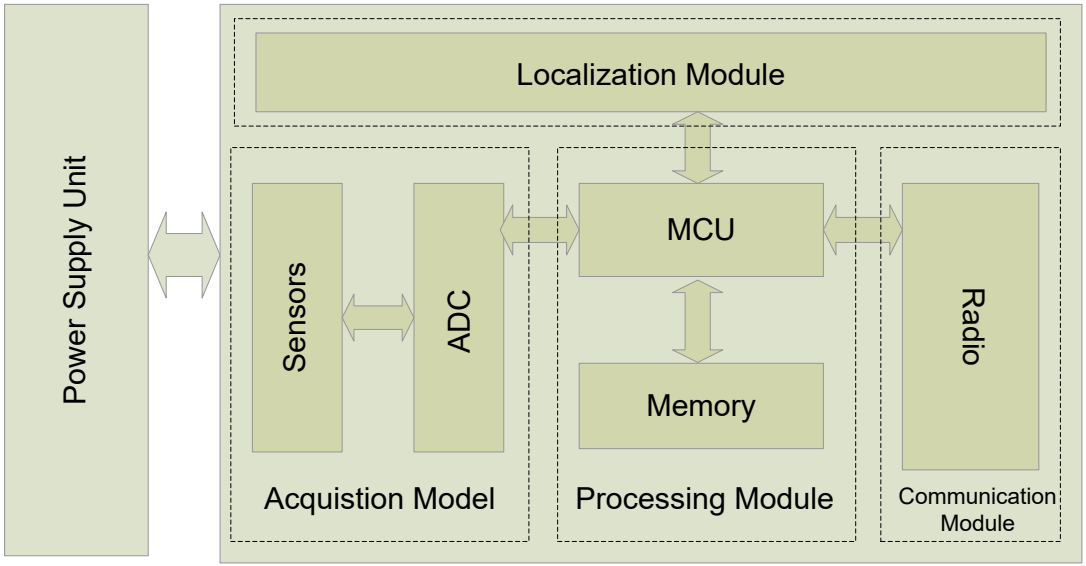
- Acquisition Module
  - monitors external conditions and tortoise's movements
  - Environmental sensors
    - ⇨ temperature, light intensity, humidity
  - 3-axis accelerometer, compass

Tortoise@: system architecture



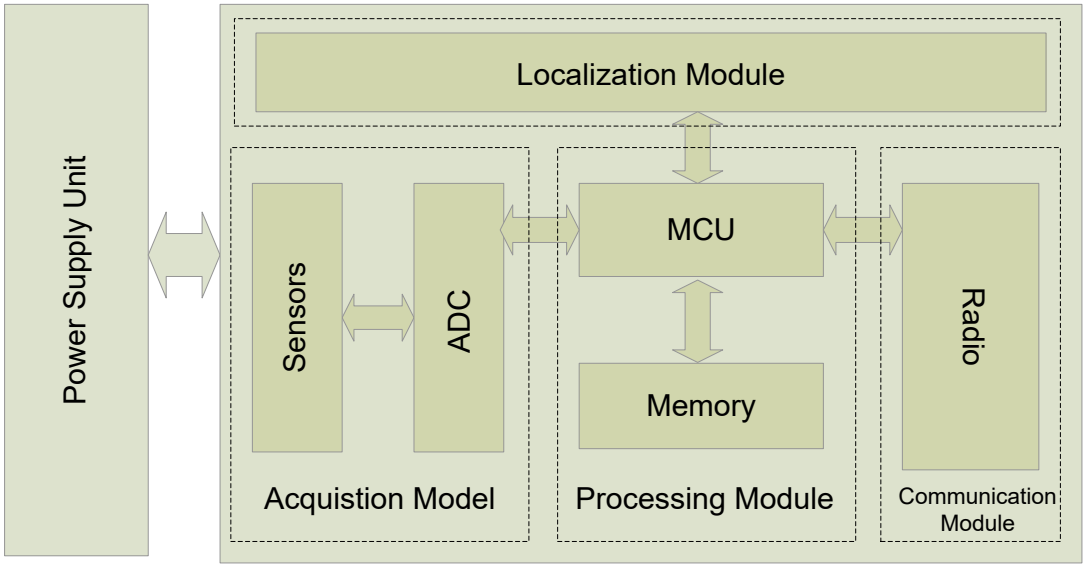
- Localization Module
  - Geographic localization system (e.g. GPS receiver)
  - Allows to localize the monitored tortoise

Tortoise@: system architecture



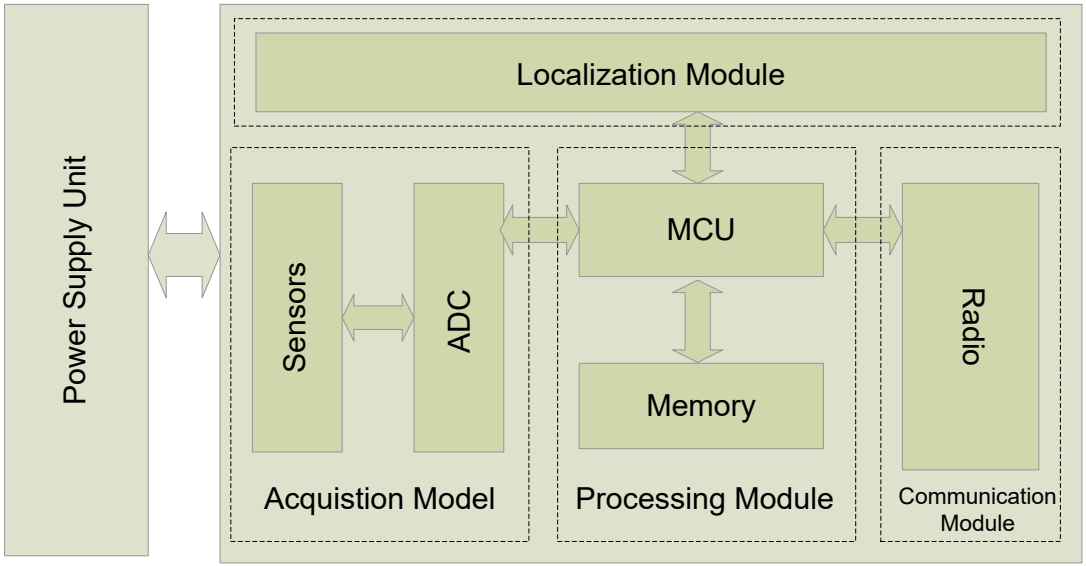
- Processing Module
  - micro-controller and (RAM + Flash) memory
  - stores and processes data received from the sensors and/or the localization module.

Tortoise@: system architecture



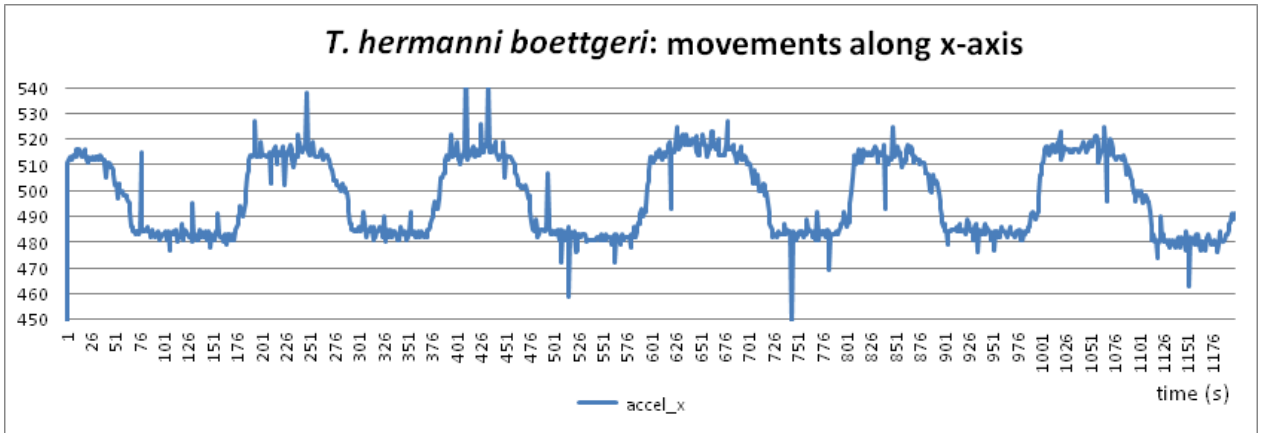
- Communication Module
  - long-range radio to communicate in real time
    - ⇨ the tortoise's location and motion direction (reported by the localization module and compass, respectively

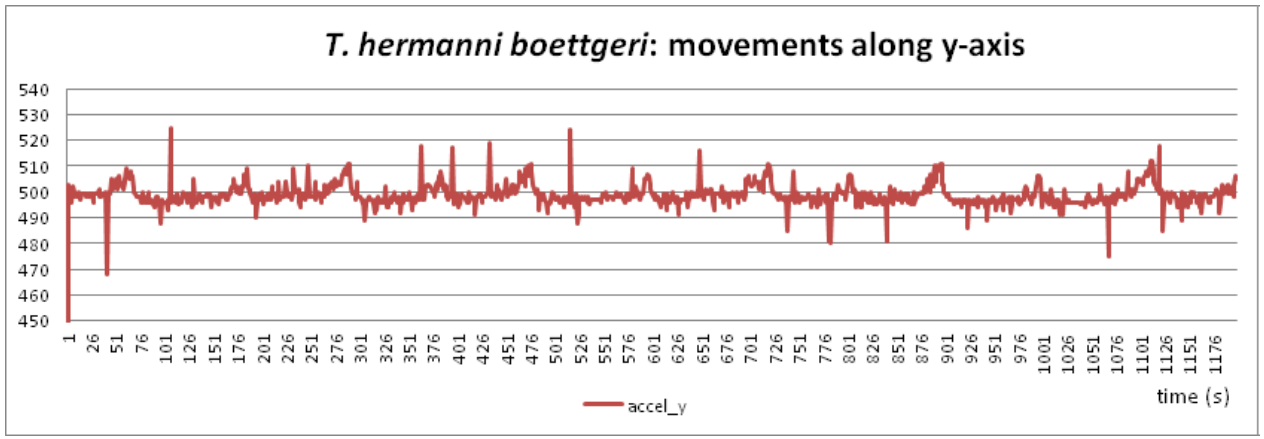
Tortoise@: system architecture



- Power Supply Unit
  - consists of one or more batteries
  - feds all the system components
  - must have a lifetime of some months
    - ⇨ Power management required

Tortoise@: experimental data

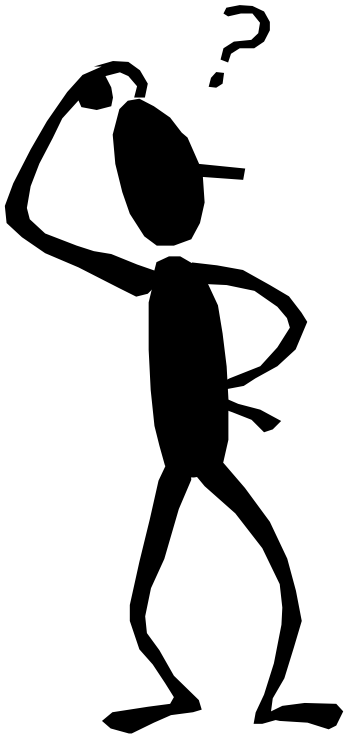




Typical movements of a *T. hermanni boettgeri* tortoise during the nest excavation phase, along the x-axis (top side) and y-axis (bottom side).

CROSSLAB
Innovation for Industry 4.0

Questions



Practical Activity

- Think of a realistic application based on
  - Passive tags (QR codes, RFIDs)
  - Active Tags (Beacons)
  - Data Loggers
  - Sensors/Sensor Nodes
- Application Requirements
  - Application Domain, Potential Users
  - Goals, User Desires
  - Requirements
- Define the overall system
  - Services
  - Overall architeture
  - Components
  - Functionalities provided by each component
  - ...