EPFL

Disal

Signals, Instruments, and Systems – W13

Sensor Systems for Environmental Monitoring & Overall Course Conclusion

Outline

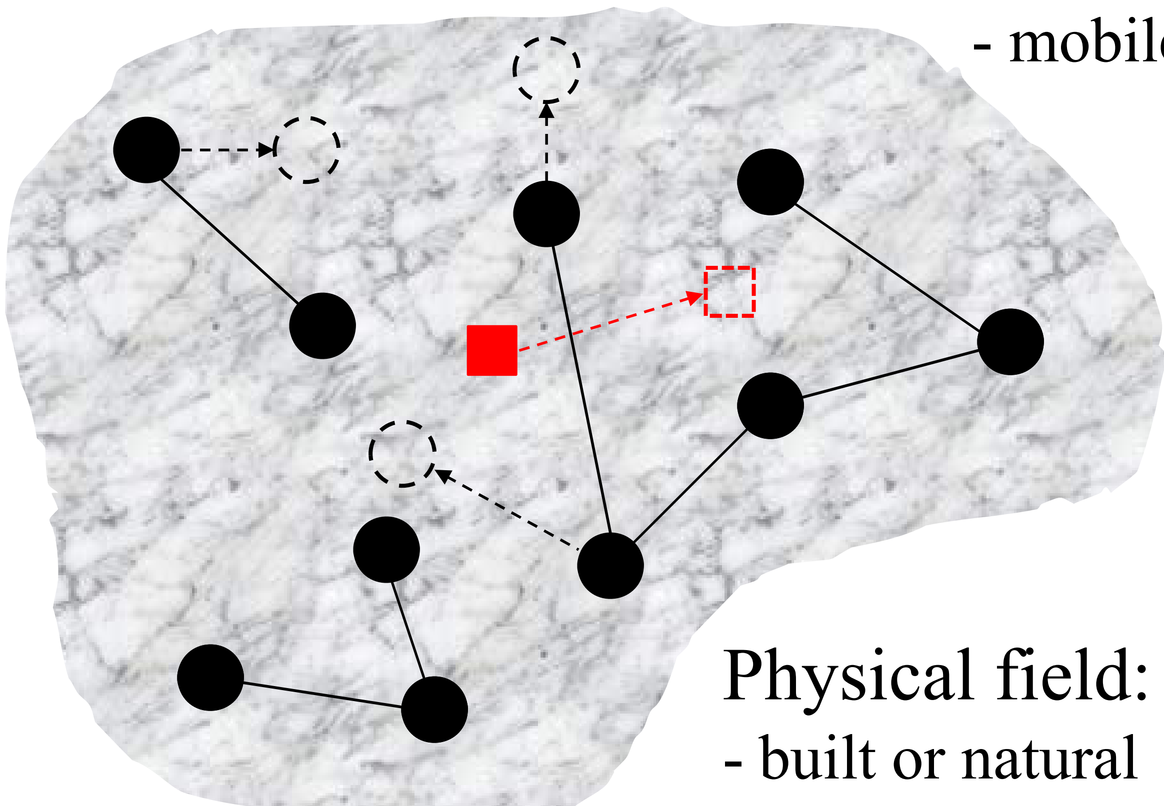
- Motivation
- Static sensor systems
- Mobile sensor systems
- Robotic sensor systems
- Overall course conclusion

Motivation

Environmental Monitoring

Typical solution in environmental monitoring:
- sparse sensing
- expensive
- field estimation via models
- possible mobility

Distributed solution for augmentation:
- size, cost
- number
- networked
- mobile



Physical field:
- built or natural
- bounded or unbounded
- 2D or 3D

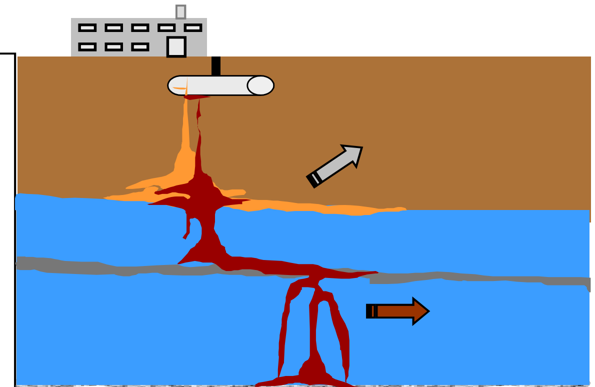
A Scientific Motivation for In-Situ Sensor Systems

Seismic Structure response

Marine Microorganisms

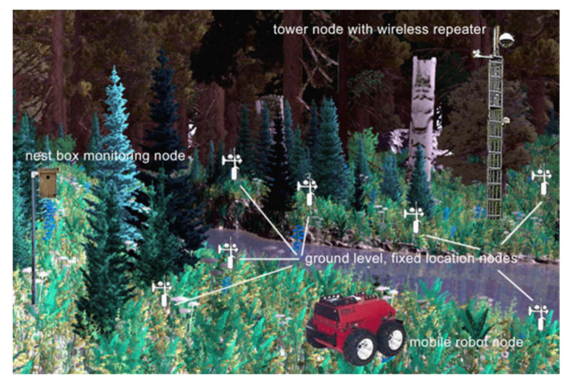
Source: D. Estrin, CENS-UCLA

- Micro-sensors, on-board processing, and wireless interfaces all feasible at very small scale
  - can monitor phenomena "up close"
- Will enable **spatially and temporally dense** environmental monitoring
- **Embedded networked sensing will reveal previously unobservable phenomena**



Contaminant Transport

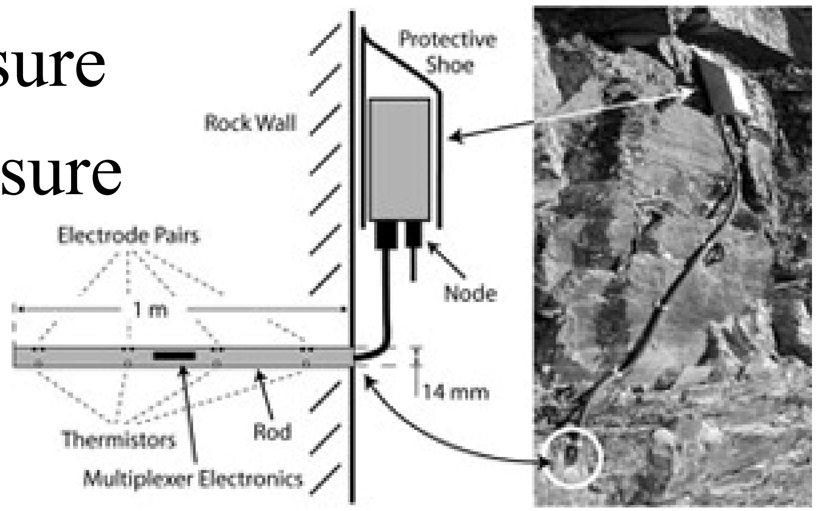
Ecosystems, Biocomplexity

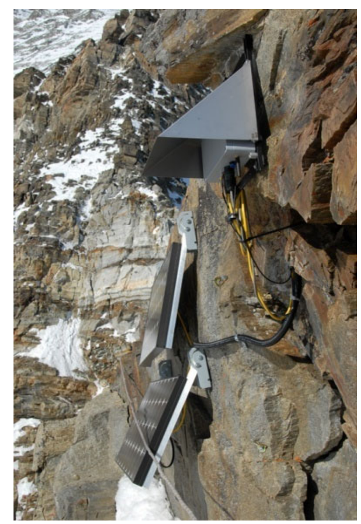


Examples of Static Sensor Systems

Permafrost Monitoring
Permasense

- What is measured:
  - rock temperature
  - rock resistivity
  - crack width
  - earth pressure
  - water pressure



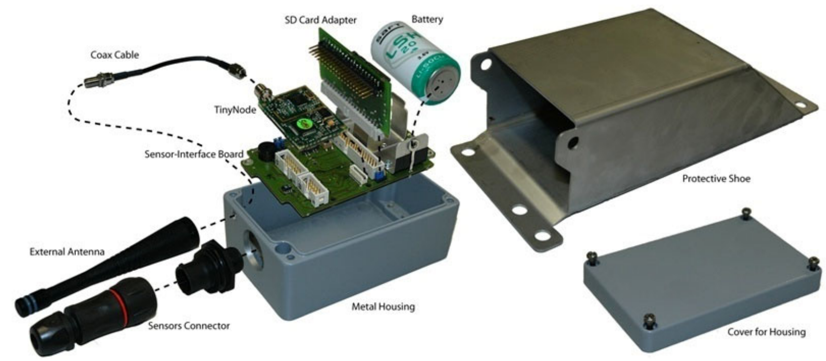


Pictures: courtesy of Permasense

Permafrost Monitoring
Permasense

- Why:

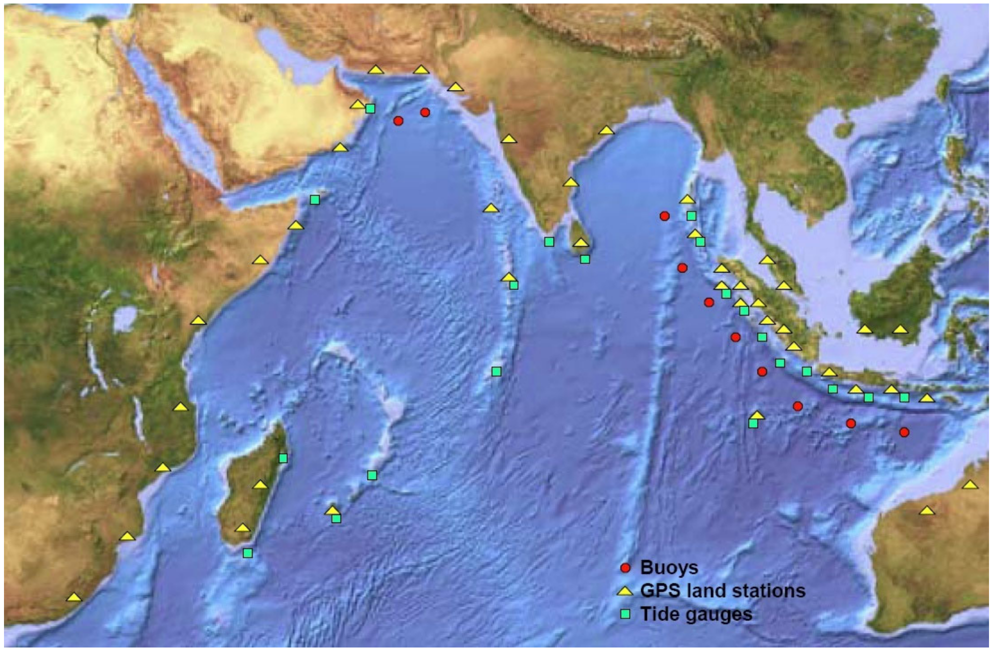
  "[…] gathering of environmental data that helps to understand the processes that connect climate change and rock fall in permafrost areas"



Pictures: courtesy of Permasense

Tsunami Early Warning System
GITEWS

- German-Indonesian effort
- What is measured:
  - seismic events
  - water pressure

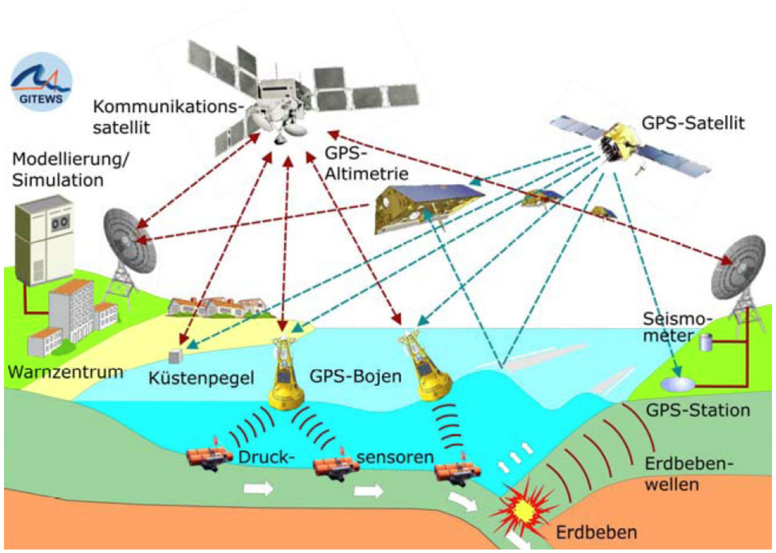


Pictures: courtesy of Deutsches GeoForschungsZentrum (GFZ)

Tsunami Early Warning System *GITEWS*

- Why:

  To detect seismic events which could cause a Tsunami. Detect a Tsunami and predict its propagation.



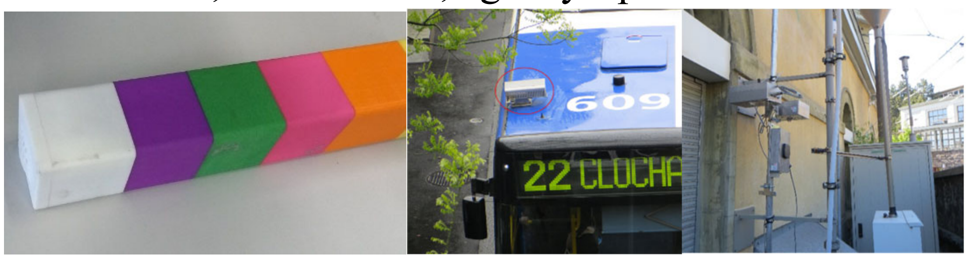
Pictures: courtesy of Deutsches GeoForschungsZentrum (GFZ)

Examples of Mobile Sensor Systems

OpenSense: Air Pollution Monitoring

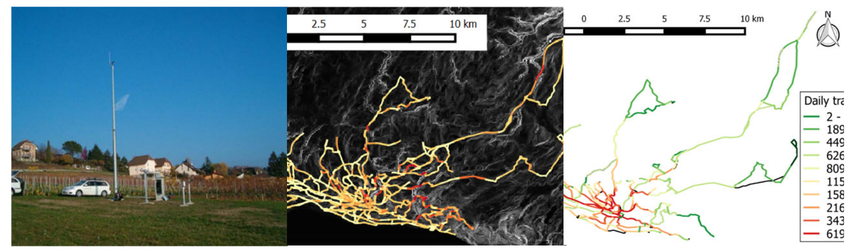
Measurement data

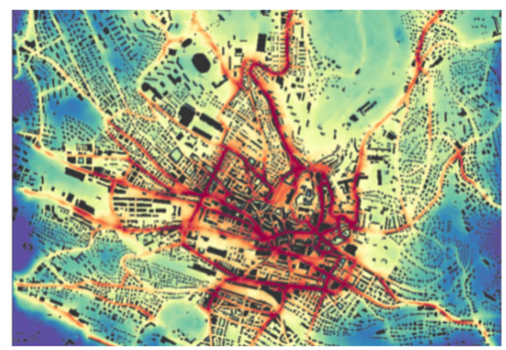
Citizen-, consortium-, agency-operated sensors



Explanatory Variables

Land-use, meteorology, traffic





Exposure information

Personal reccomendations, health studies, urban planning, crowdsensing

High-resolution pollution maps

Spatiotemporally flexible, modeling;
emphasis on data-driven statistical modeling methods

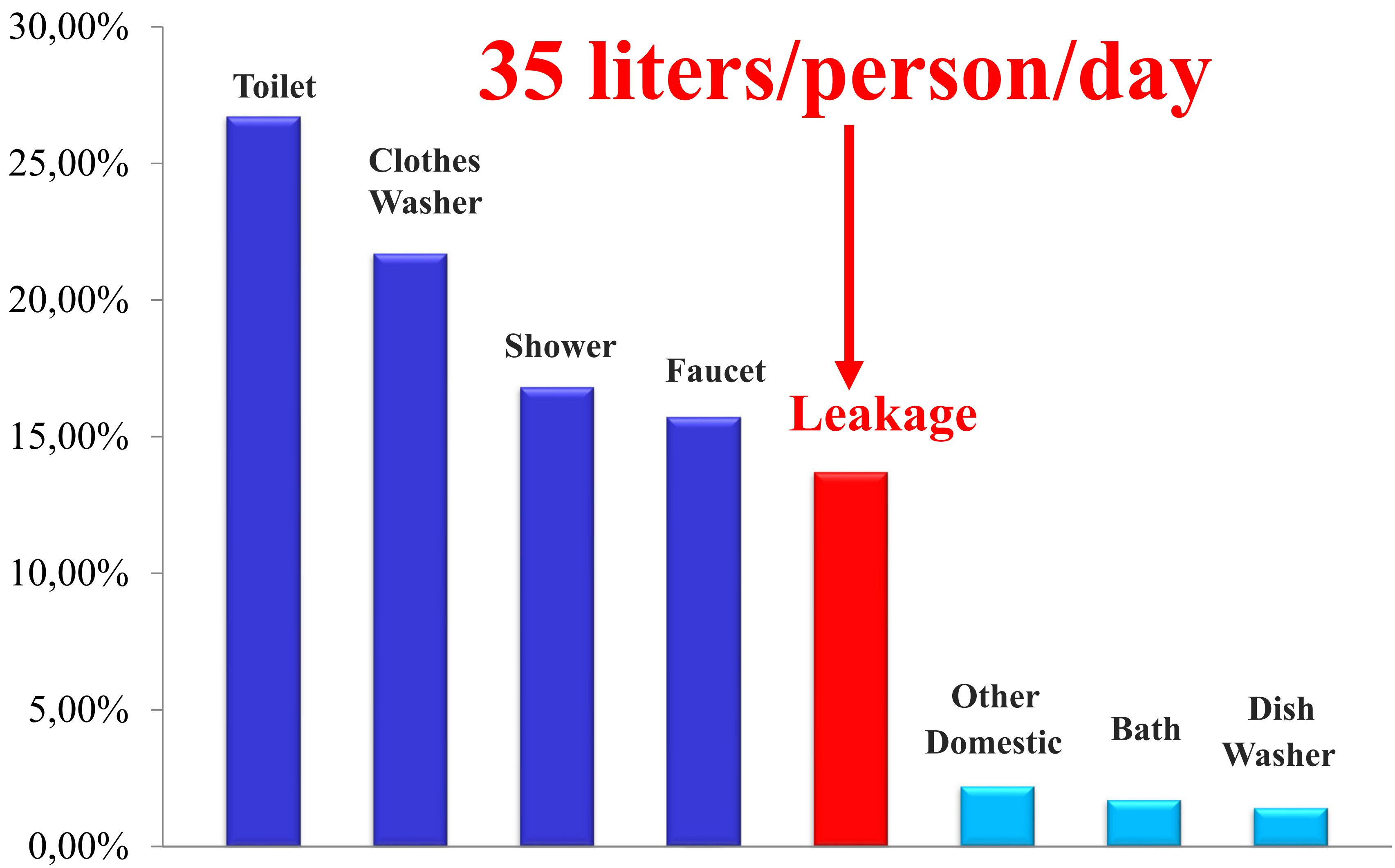
PipeProbe

A Mobile Sensor Droplet for Mapping Hidden Pipeline

Tsung-te (Ted) Lai
Yu-han (Tiffany) Chen
Polly Huang
Hao-hua Chu

National Taiwan University

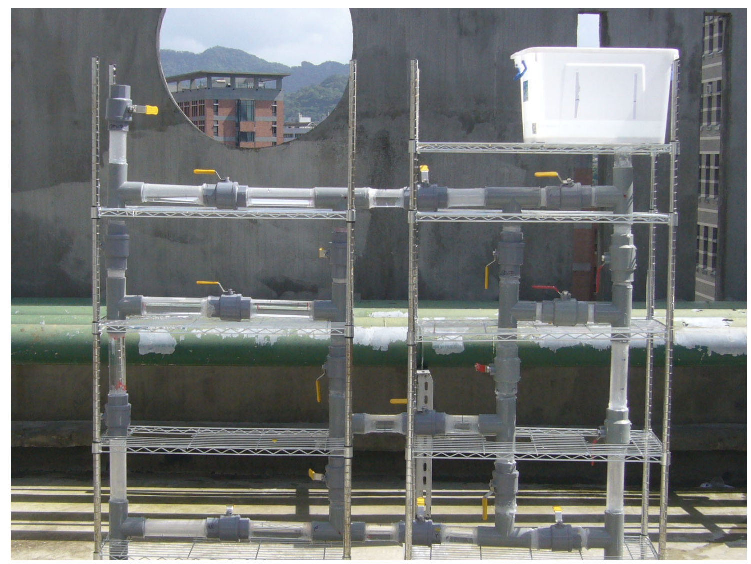
Residential Water Usage



Source: Residential End Uses of Water, AWWA Research Foundation

PipeProbe System

- Map 3D spatial topology of water pipelines
- Leverage natural water flow for mobility
- 13mm(L) x 11mm(W) x 7mm(H), 3 grams
- IT basis: ECo wireless sensor mote (Pai Chou, UC Irvine)
- Com: radio
- Sensors: pressure, 3-axis accelerometer, gyroscope

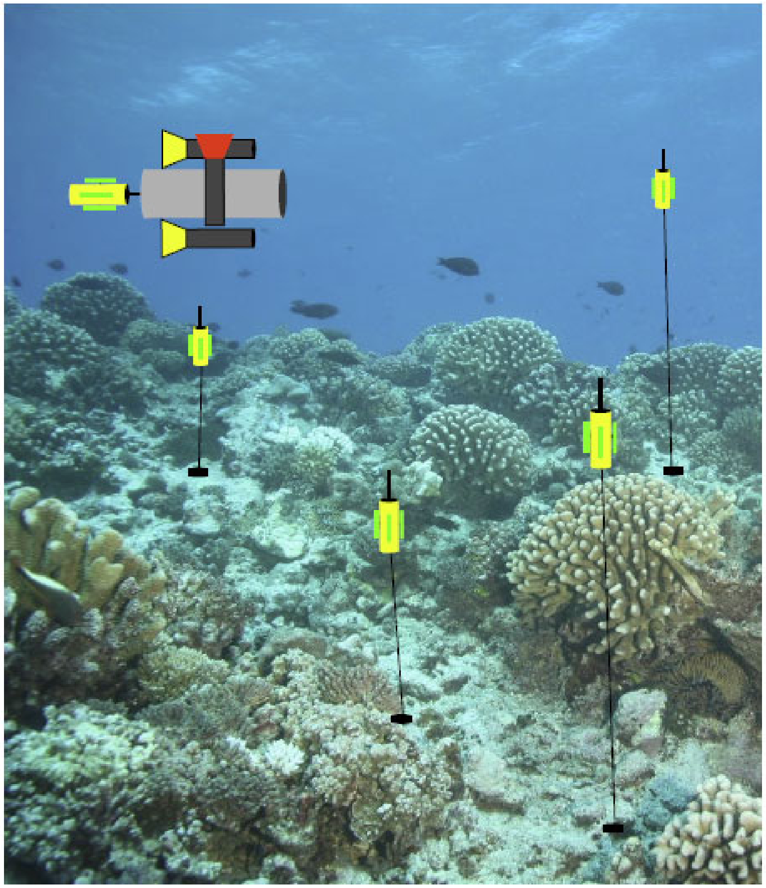


[From Lai et al., University of Taiwan]
http://mll.csie.ntu.edu.tw/index.php

Examples of Robotic Sensor Systems

Monitoring Coral Reefs

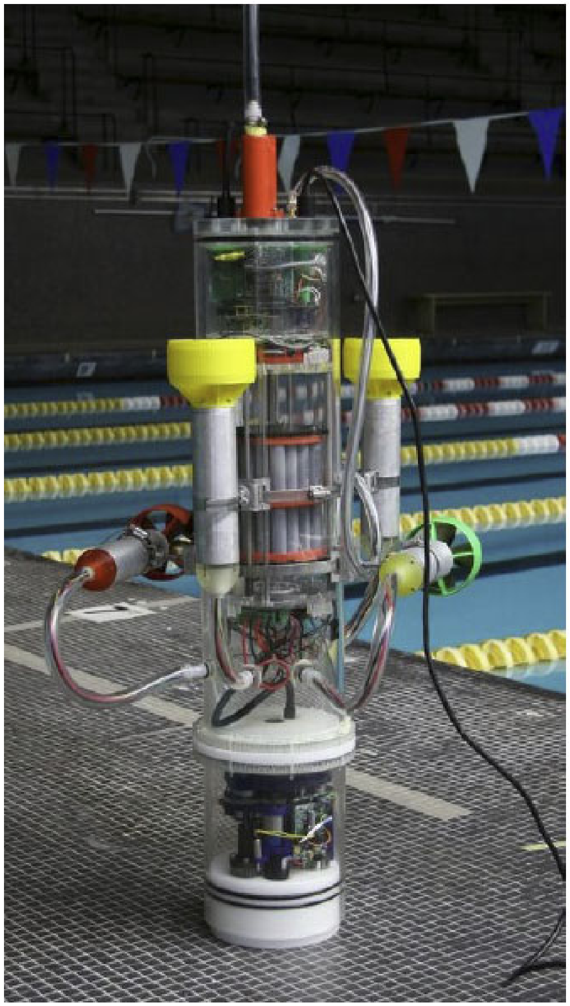
- Automatically deploy sensors
  - To save energy
- Optimally place sensors
  - For improved sensing
- Communication between sensors and robot
  - For near real-time feedback



Note: underwater robots are also called Underwater Autonomous Vehicles (AUVs)

[From C. Detweiler, D. Rus et al, MIT]

Monitoring Coral Reefs – The AMOUR robot

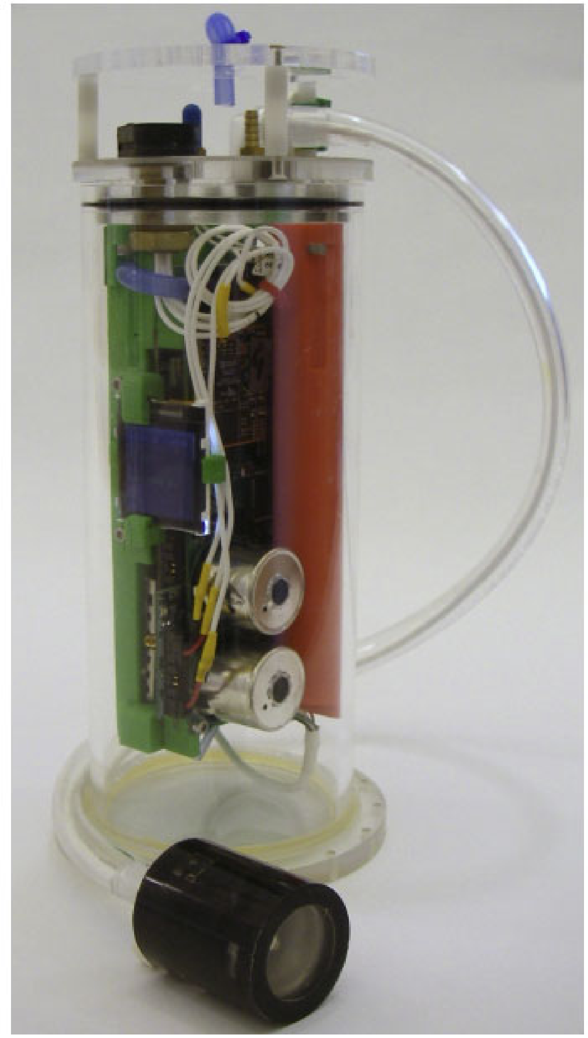


- Easily deployed: 25.5 Kg 0.86m
- Shallow water operation (over 50m)
- 5 500W thrusters
  - 1.3 m/s
- >500Wh Li-Ion battery
  - 8km range
  - 6 hour typical operation time
- Vertical & horizontal orientation
- Adjustable buoyancy and balance
- On-board logging and sensing
  - Camera, depth, temperature, salinity, dissolved oxygen
- Acoustic, optical, & radio communication

[From C. Detweiler, D.Rus et al., MIT]

Monitoring Coral Reefs – TheAquaNodes

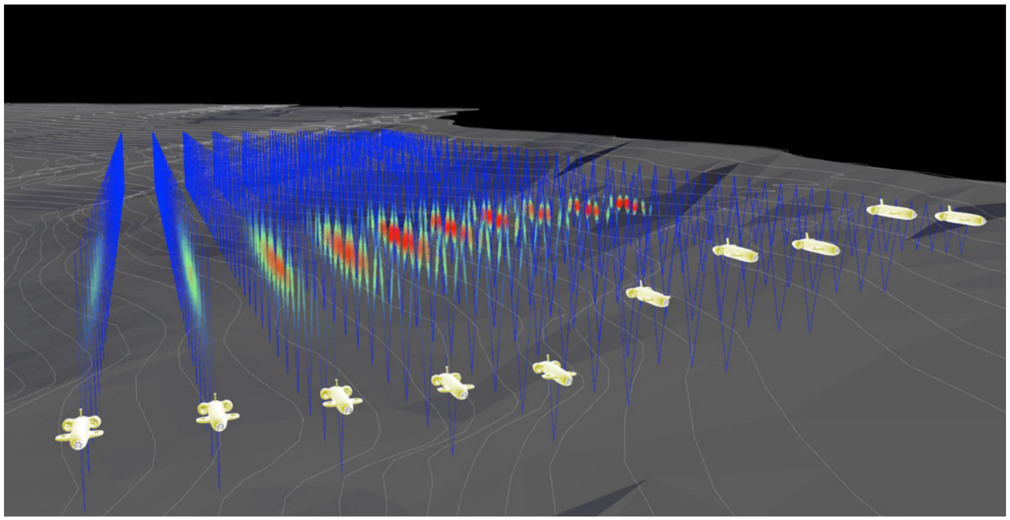
- Processor/Logging
  - LPC2148 60MHz ARM
  - SD Card
- Communications
  - Acoustic: 300b/s
  - Radio: 57kb/s on surface
  - Optical: 1Mb/s
- Sensors
  - Temperature, pressure, salinity, dissolved oxygen
  - Camera
  - Other digital and analog inputs
- Depth Adjustment
  - 0.5m/min

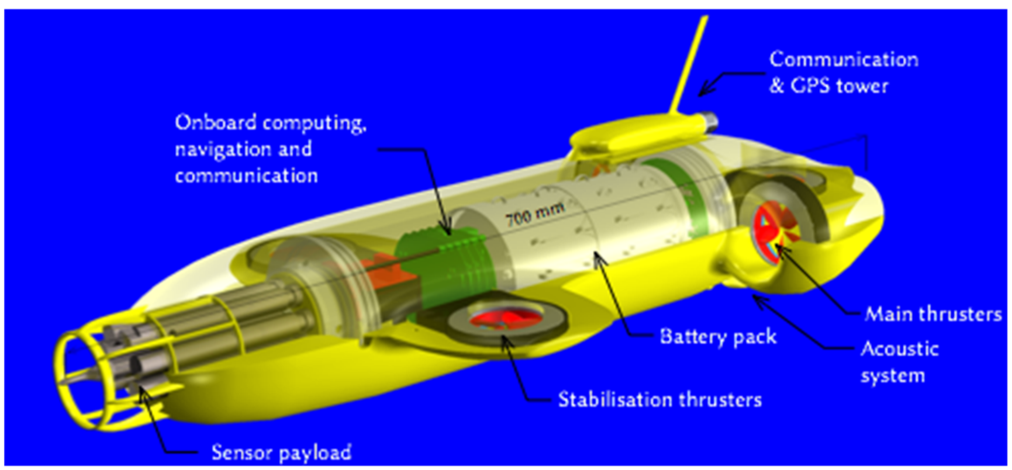


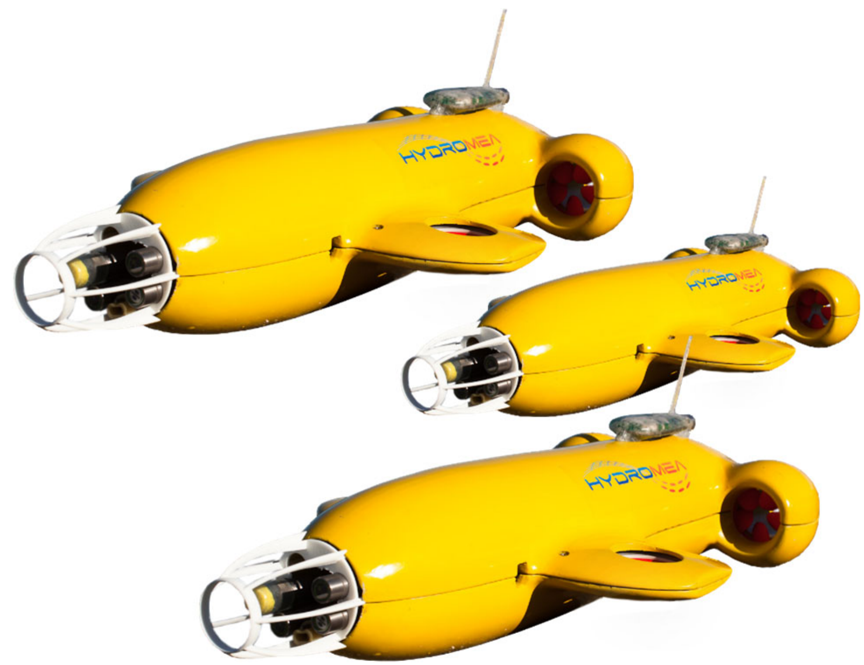
[From C. Detweiler, D.Rus et al., MIT]

Vertex AUVs for Limnology

[SNSF Sinergia project, 2015-2019 Martinoli, Wueest, Ibelings; key personnel: Bahr, Schill]

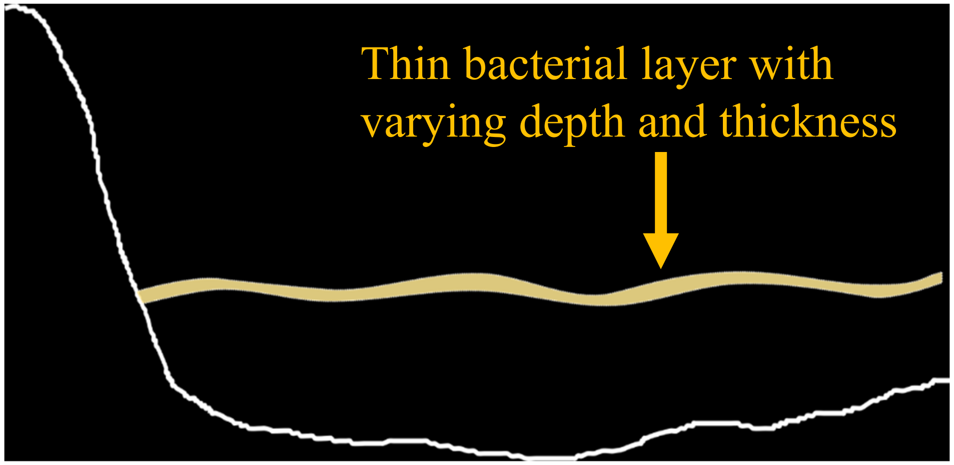




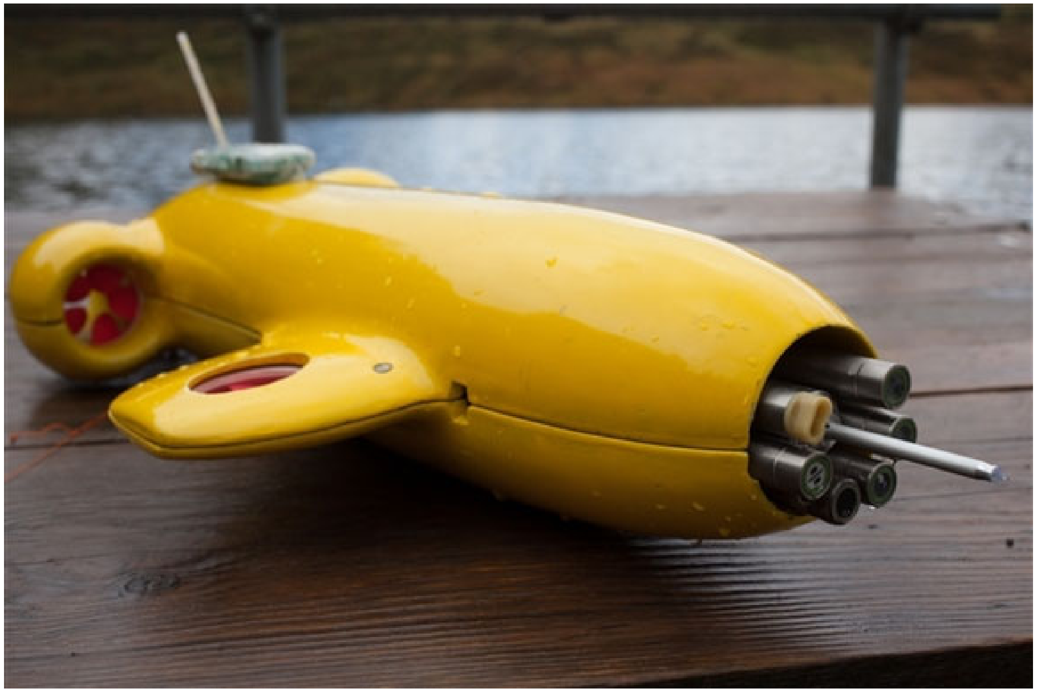


A Mission Example

- Measuring within a thin stratified bacterial layer in Lake Cadagno (TI)
- Varying depth and thickness
- High resolution temperature measurements *within the layer* to capture bacterial activity
- Added value of an AUV in respect to traditional instruments (vertical profilers): assessment of horizontal variations of the bacterial layer



The Vertex AUV and its Sensing Payload



Equipped with a suite of sensors including Turbidity, Chlorophyll and a High Resolution Fast **(20 μK, 400 Hz)** Temperature Sensor

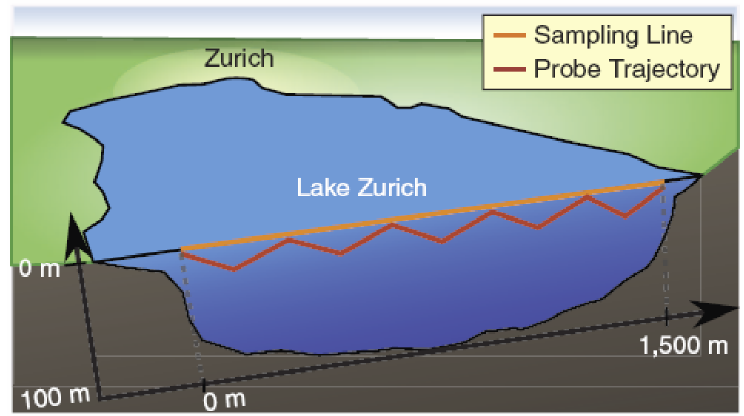
Mission Video

[Quraishi et al., ICRA 2018]

Video and additional material at:
https://www.epfl.ch/labs/disal/research/auvdistributedsensing/

Lake Monitoring with an Autonomous Surface Vehicle

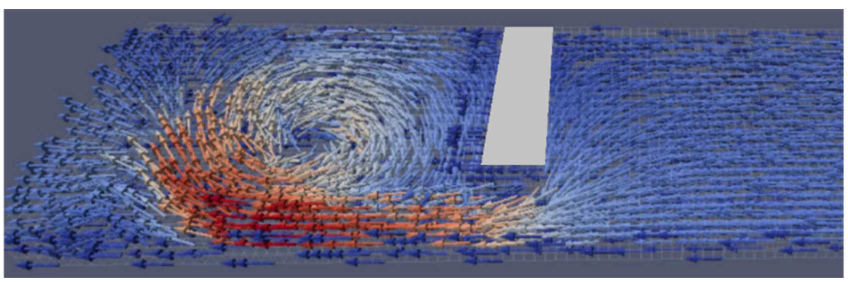
[Hitz et al, *IEEE RAM* 2012]

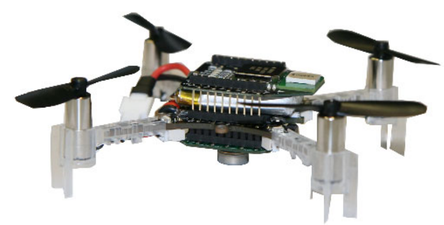


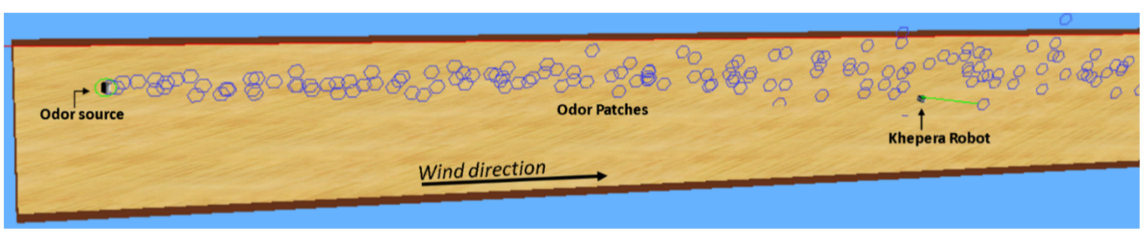
- Autonomous Surface Vehicle (ASV) Lizhbeth
- Inland water monitoring (deployed in lake Zurich)
- Probe controlled by winch from surface to up to 20 m depth
- Limnological parameters measured (including temperature profile)

Gas Source Localization and Distribution Mapping

- Probabilistic and bio-inspired algorithms
- Wind tunnel experiments and simulation tools
- Ground and aerial vehicles equipped with gas and wind sensors







[Rahbar et al. ICRA 2019, 2020; Ercolani and Martinoli IROS 2020]

Gas Source Localization – Video

[Rahbar et al. ICRA 2020]

International Conference on Robotics and Automation (ICRA 2020)

A Distributed Source Term Estimation Algorithm for Multi-Robot Systems

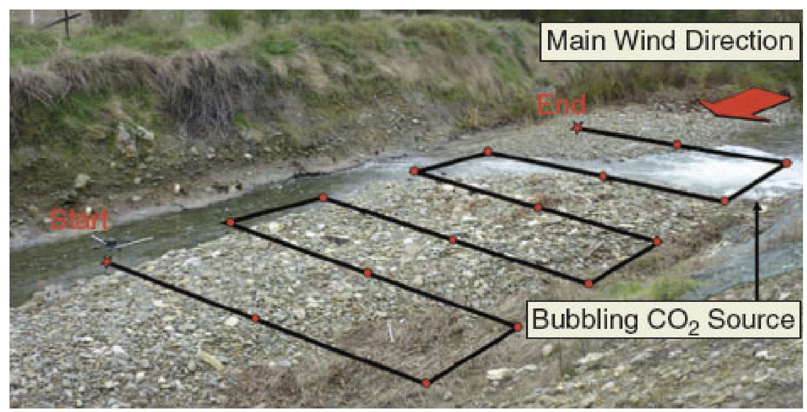
Faezeh Rahbar and Alcherio Martinoli

Distributed Intelligent Systems and Algorithms Laboratory,
École Polytechnique Fédérale de Lausanne, Switzerland

Video and additional material at:
https://www.epfl.ch/labs/disal/research/odorsourcelocalization/

Gas Source Localization and Distribution Mapping

- Chemical sensor probe
- Wind direction indirectly estimated using typical on-board navigation sensors
- Chemical mapping/source localization
- Wind tunnel and outdoor experiments



[Neumann et al, *IEEE RAM* 2012]

Conclusion

Take Home Messages

- The area of sensor systems is booming for all sort of applications
- A lot of these applications are directly concerning the natural and built environment
- They are characterized by various degree of mobility (manually deployable, parasitic mobility, or controlled mobility)
- Totally new, unprecedented, and often distributed instruments are developed in the research labs and are becoming available on the market via various start-ups
- Intelligent instruments are very powerful and characterized by an increased software complexity which offer new opportunities in terms of customization, automation, etc.

Additional Literature – Week 13

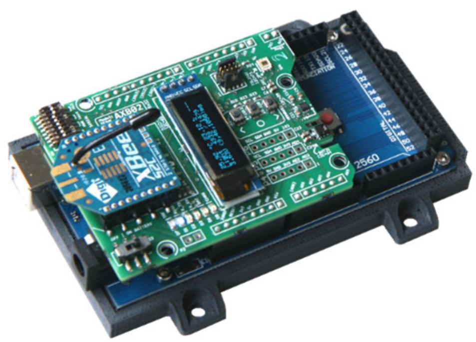
- Permasense: https://www.permasense.ch/
- GITEWS: https://www.gitews.de
- Sensorscope: https://www.sensorscope.ch
- OpenSense: http://opensense.epfl.ch
- Aquatic microbic observing systems
  https://robotics.usc.edu/~namos/index.html
- Autonomous Undersea Vehicle Applications Center
  https://auvac.org/
- Adapting sampling of oceans
  https://www.princeton.edu/~dcsl/asap/
- Monitoring coral reefs:
  https://groups.csail.mit.edu/drl/wiki/index.php?title=AMOUR

Course Take Home Messages

(Intelligent) Instruments as Specialized Embedded Systems

e-puck

Vertex

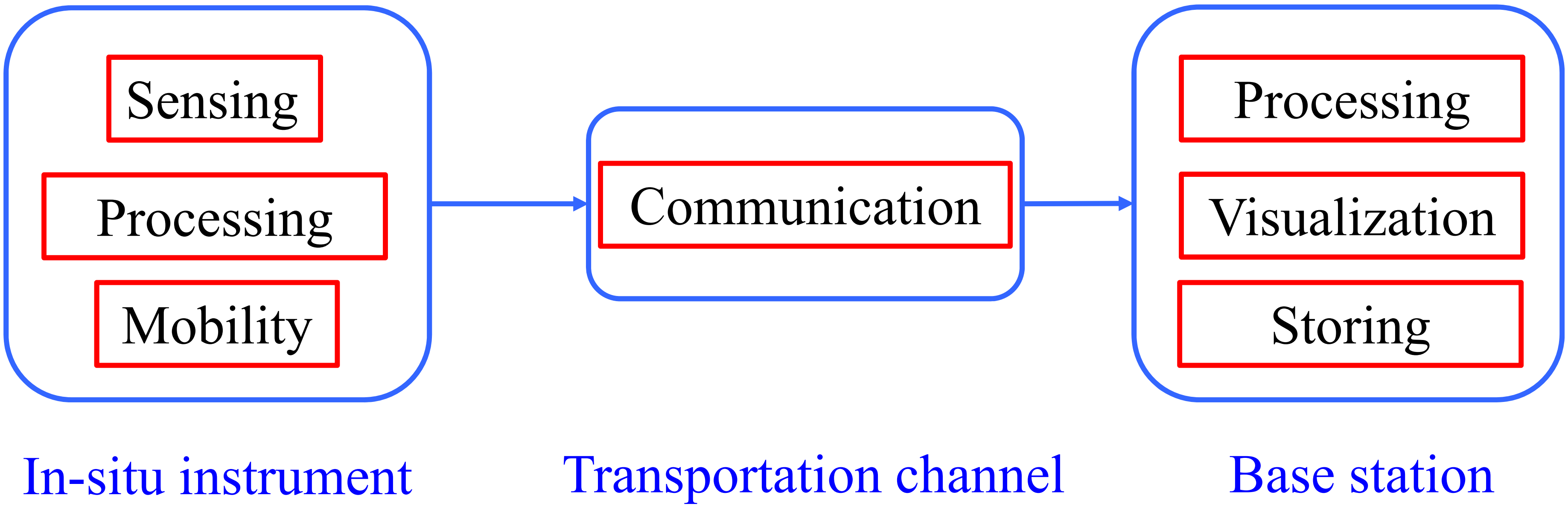


DISAL Arduino Xbee

Sensorscope station

Handheld Airborne Mapping System

What These Systems Share at their Core?



The goal of this course is to shed light on this process and blocks!

What This Course Is About

- Fundamentals of signal processing:
  - Analog/digital signals, sampling and reconstruction
  - Time/frequency domains and transforms
  - Filters, converters
- Fundamentals of embedded systems:
  - Programming skills consolidation (interpreted vs. compiled languages)
  - Basic control, localization, communication, and estimation techniques
  - C programming for embedded systems
  - C programming for mobile robotic systems
  - Sensing and sensor systems

Severely impacted by pandemic restrictions

Our Main Objectives for This Course

This course should allow you:

- To become a power user of the field instruments in environmental engineering used nowadays (sensor networks, meteorological stations, data loggers, etc.) and in even more so in the future (exploratory and cleaning robots, robotic sensor systems, etc.)
- To transport your domain knowledge into code to be deployed into programmable instruments
- To collaborate more efficiently with other engineers (e.g., computer, electrical, mechanical)
- To cumulate additional background to attend, if any interest, courses of the specialization on Environmental Monitoring and Modeling including our course on Distributed Intelligent Systems

Thank you for your attention!