Signals, Instruments, and Systems – W13

Environmental Sensor Networks: From Static to Robotic Nodes

&

Overall Course Conclusion
Outline

• Motivation
• Examples of real deployments
  • Static sensor networks
  • Mobile sensor networks
  • Robotic sensor networks
• Overall course conclusion
Motivation
Problems in Distributed Sensing

Current solution:
- sparse sensing
- expensive
- field estimation via models
- possible mobility

Possible missions:
- patrolling
- searching
- mapping
- monitoring

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

Distributed solution:
- size, cost
- number
- networked
- mobile
A Scientific Motivation for Sensor Networks

- 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

Source: D. Estrin, CENS-UCLA
Deployment Examples - Static Sensor Networks
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)*
Deployments Examples - Mobile Sensor Networks
OpenSense: Air Pollution Monitoring

http://opensense.epfl.ch

Measurement data
Crowdsensors, mobile sensors, monitoring stations

Land-use and weather
Terrain, meteorology, emission sources, population

Officials, citizens
Health studies, crowdsensing methods

High-resolution pollution maps
Physics-based and data-driven modeling methods
PipeProbe

A Mobile Sensor Droplet for Mapping Hidden Pipeline

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Yu-han (Tiffany) Chen
Polly Huang
Hao-hua Chu

National Taiwan University
Residential Water Usage

35 liters/person/day

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
Deployment Examples - Robots and Robotic Sensor Networks
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]
Multi-AUVs for Limnology

[SNSF Sinergia project, 2015-2019
Martinoli, Wueest, Ibelings; key personnel: Bahr, Schill]
SNSF Sinergia Project – 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
SNSF Sinergia Project – The AUV and its Sensing Payload

Equipped with a suite of sensors including Turbidity, Chlorophyll and a High Resolution Fast \( (20 \mu K, 400 Hz) \) Temperature Sensor
SNSF Sinergia Project – Video

[Quraishi et al., ICRA 2018]
Autonomous Surface Vehicle (ASV)

[Hitz et al, *IEEE RAM* 2012]

- 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)
Unmanned Autonomous Vehicle (UAV)

[Neumann et al, IEEE RAM 2012]

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

Systematic experiments in a 18 x 4 x 2 m wind tunnel

Submicroscopic high-fidelity simulations

- Suite of algorithms:
  - bio-inspired
  - probabilistic
  - formation-based

- Single and multi-robot

Conclusion
Take Home Messages

• The area of sensor networks 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

• **Static sensor networks**
  - Sensorscope: [https://sensorscope.epfl.ch/](https://sensorscope.epfl.ch/), [https://www.sensorscope.ch](https://www.sensorscope.ch)
  - Permasense: [https://www.permasense.ch/](https://www.permasense.ch/)
  - GITEWS: [https://www.gitews.de](https://www.gitews.de)

• **Mobile sensor networks**
  - OpenSense: [http://opensense.epfl.ch](http://opensense.epfl.ch)
Additional Literature – Week 13

• Robotic sensor nodes and networks
  – Aquatic microbial observing systems
    https://robotics.usc.edu/~namos/index.html
  – Adapting sampling of oceans
    https://www.princeton.edu/~dcs1/asap/
  – Robots and sensor networks systems for underwater monitoring
  – IEEE Robotics and Automation Magazine, special issue on
    Robotics for Environmental Monitoring, M. Dunbabin and L. Marques, editors, March 2012
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?

- Sensing
- Processing
- Mobility

- Communication

- Processing
- Visualization
- Storing

In-situ instrument  Transportation channel  Base station

The goal of this course is to shed light on this process and blocks!
What Did We Cover?

• Fundamentals of computer science:
  – Basics of computer architecture
  – C programming consolidation (vs. Matlab)
  – C for embedded and real-time systems

• Fundamentals of signal processing:
  – Analog/digital signals, sampling and reconstruction
  – Time/frequency domains and transforms
  – Filters, converters

• Fundamentals of embedded systems:
  – Microprocessors, microcontrollers, memory
  – Sensors and actuators
  – Basic control and communication techniques and concepts
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, robotics sensor networks, 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!