Sensor Networks: Evolution, Opportunities, and Challenges

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Outline

- Why is sensor network exciting?
- Where did it come from?
  - History
  - Examples
- Problems and challenges
- Where is it going?
- Conclusions
Why is sensor network exciting?

- Business Week: one of the 21 most important technologies for the 21st century
- Sense, communicate, and compute
  - Things without our presence
- Monitor and gather information
  - In places not easily accessible
- Querying and tasking
  - Act on up-to-date data to develop timely new strategies
- Networked sensors deployed all around the world
  - Controlling homes, cities, and the environment
Attributes of sensor networks

| Sensors | Size: small (e.g., micro-electro mechanical systems (MEMS)), large (e.g., radars, satellites)  
|         | Number: small, large  
|         | Type: passive (e.g., acoustic, seismic, video, IR, magnetic), active (e.g., radar, ladar)  
|         | Composition or mix: homogeneous (same types of sensors), heterogeneous (different types of sensors)  
|         | Spatial coverage: dense, sparse  
|         | Deployment: fixed and planned (e.g., factory networks), ad hoc (e.g., air-dropped)  
|         | Dynamics: stationary (e.g., seismic sensors), mobile (e.g., on robot vehicles) |
| Sensing entities of interest | Extent: distributed (e.g., environmental monitoring), localized (e.g., target tracking)  
|         | Mobility: static, dynamic  
|         | Nature: cooperative (e.g., air traffic control), non-cooperative (e.g., military targets) |
| Operating environment | Benign (factory floor), adverse (battlefield) |
| Communication | Networking: wired, wireless  
|         | Bandwidth: high, low |
| Processing architecture | Centralized (all data sent to central site), distributed (located at sensor or other sites), hybrid |
| Energy availability | Constrained (e.g., in small sensors), unconstrained (e.g., in large sensors) |
Versatility of sensor networks

- Military sensing
- Physical security
- Video surveillance
- Distributed robotics
- Environmental monitoring
- Traffic control and surveillance
- Building and structures monitoring
- Industrial and manufacturing automation
Where did it come from?

- Cold War
  - SOSUS (Sound Surveillance System) – acoustic sensors
    - Detect quiet Soviet submarines
  - Monitor events in the ocean (e.g., seismic and animal activity)
    - Marine Mammal Sounds
      - Atlantic blue whale call 🎵
      - South Pacific blue whale call 🎵
Where did it come from? (cont.)

- Deep Ocean Seismicity from Hydroacoustic Monitoring
  - earthquake swarm occurred overnight on NE Pacific Endeavour Ridge (2/27/05)
  - maps showing the location of the Endeavour earthquake swarm

[Image of map showing earthquake location]
History

- Early research
  - Adopt a hierarchical processing structure, information processed in a consecutive order
  - Human operators needed
- 20th century
  - DSN (Distributed Sensor Networks)
    - Provide a network allows flexible and transparent access
  - Network-centric warfare by CCRP (Command and Control Research Program)
    - Information sharing and collaboration among sensors
      - Enables self-synchronization
      - Increase robustness of sensor networks
- 21st century
  - SensIT (Sensor Information Technology) by DARPA (Defense Advanced Research Projects Agency)
    - Suitable for highly dynamic ad hoc environments
    - Provide reliable and timely information
### Three Generations of Sensor Nodes

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Custom contractors, e.g., for TRSS</td>
<td>Commercial: Crossbow Technology, Inc. Sensoria Corp., Ember Corp.</td>
<td>Dust, Inc. and others to be formed</td>
</tr>
<tr>
<td>Size</td>
<td>Large shoe box and up</td>
<td>Pack of cards to small shoe box</td>
<td>Dust particle</td>
</tr>
<tr>
<td>Weight</td>
<td>Kilograms</td>
<td>Grams</td>
<td>Negligible</td>
</tr>
<tr>
<td>Node architecture</td>
<td>Separate sensing, processing and communication</td>
<td>Integrated sensing, processing and communication</td>
<td>Integrated sensing, processing and communication</td>
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<tr>
<td>Topology</td>
<td>Point-to-point, star</td>
<td>Client server, peer to peer</td>
<td>Peer to peer</td>
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<tr>
<td>Power supply lifetime</td>
<td>Large batteries; hours, days and longer</td>
<td>AA batteries; days to weeks</td>
<td>Solar; months to years</td>
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<tr>
<td>Deployment</td>
<td>Vehicle-placed or air-drop single sensors</td>
<td>Hand-emplaced</td>
<td>Embedded, “sprinkled” left-behind</td>
</tr>
</tbody>
</table>

**Image:**
- TRSS Node
- Crossbow
- Ember
- Sensoria
- Dust, Inc.
Applications

Infrastructure Security

- Networks of sensors deployed around facilities
- Detection and tracking of possible threats
- Early warnings and rapid coordinated responses to potential threats
- Example: Livermore National Laboratory
  - correlated sensor networks can communicate with each other to ignore false alarms and detect signal not quite at threshold by correlating spatial and temporal information from other sensors
  - independent sensors do not have temporal information to discriminate false alarms
More recent applications

- Distributed tracking in wireless ad hoc networks
  - IDSQ (information-driven sensor querying)
    - Each sensor
      - Computes the predicted information of a piece of nonlocal sensor data
      - Determine from which sensor to request data
    - Manage resource constraints
    - Decrease cost of transmitting information

Source tracking in a large-scale sensor network via computations over a sequence of subnetworks formed by the detecting nodes in the vicinity of the source.
Environment and habitat Monitoring

SIVAM (System for the Vigilance of the Amazon)
- Provides large scale electronic surveillance of Brazil's immense and relatively undeveloped Amazon region
- A suite of sensors provides data to
  - Three regional operations centers
  - One national operations center
  - Air surveillance center
  - ALL NETWORKED TOGETHER

Sensors
- Radar (aircraft), satellite imagery (space), environmental sensors (ground)
Applications (cont.)

SIVAM (cont.)

- Goals
  - Prevention and control of epidemics
  - Environmental protection
  - Control of land occupation and use
  - Economical and ecological zoning
  - Mapping
  - Protection of indigenous populations
  - Border surveillance and control
  - Monitoring river navigation
  - Monitoring forest fires
  - Law enforcement/ drug trafficking
  - Air traffic control and surveillance for both cooperative and non-cooperative aircraft
Other examples of sensor networks

- Industrial sensing
  - Access regions inaccessible by humans
  - Monitor machine health

- Spectral sensors
  - Sensors acquire spectra as data
    - Environmental sensing (electromagnetic spectrum)
      - To monitor the atmosphere (e.g., greenhouse effect)
Hard problems and challenges

- **Sensors networks**
  - Uncertain and dynamic environment
  - Energy and bandwidth constraints
  - Problems in communication, sensor management, and data processing

- **Ad hoc network discovery**
  - Network topology constructed in real time
    - Adapt to unpredictable environment
    - Know the identity and location of neighbors
    - Know self location
Hard problems and challenges (cont.)

- Network control and routing
  - Developing self-configuring network system
    - Deal with changing resource requirements and adapt routing dynamically
    - Provide adequate survival of the network in a changing environment
    - Balance the tradeoffs between latency, reliability, and energy
Hard problems and challenges (cont.)

- Collaborative signal and information processing (balance)
  - Performance vs. resource utilization
    - More sensors processing data, better performance, but use more communication resources (i.e. energy)

- Performance vs. robustness
  - Design desired algorithm to achieve robustness
    - E.g., highly accurate or fail-safe results
  - Without sacrificing performance
Hard problems and challenges (cont.)

### Tasking and querying
- In sensor network, the data is constantly being acquired, updated, lost and then reacquired
- Traditional database style querying may not be adequate
- Need a flexible, reliable, and simple interface to query and task the system that account for changes in the sensor network in a timely fashion

### Security
- Utmost concern in nearly all applications of sensor network
- Protect military intelligence or privacy
- Need to be survivable, protected against intrusion and spoofing
- Not easily detectable by enemies or hackers
Where is it going?

- Smaller and cheaper sensors, more capable and versatile (to nanobots?)
- More advanced wireless networks
  - IEEE 802.15 standard
    - Low energy and high bandwidth
    - Low cost sensor nets
    - Deployed in large numbers
    - Provide a standard way for communication
- Highly dynamic ad hoc environment
  - Dynamic and interactive querying and tasking
- Wireless network of ubiquitous low-cost disposable microsensors
  - Smart dust
Conclusions

Sensor Networks

- Exciting emerging field
- Applications limited only by imagination
- Can affect all aspects of human life
  - Networks of small, possibly microscopic sensors embedded everywhere, even on people
  - Perform automated continual and discrete monitoring and tasks
- Ethical considerations may become important as sensor networks become ubiquitous and invade privacy
References

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Thank you!