Sensor Devices and Sensor Network Applications for the Smart Grid/Smart Cities

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Agenda

• Introduction
  - Sensors, Actuators, Transducers
• Sensor Types, Classification
• Wireless Sensor Networks (WSN)
• Sensor Devices and WSN Applications in Smart Grid, HEMS, Smart Cities
• Summary and Future Work
Introduction

Sensors/Senses

Ubiquitous, Everywhere

The iPhone has a built-in accelerometer (motion detector). Uses include:

- Game control
- Navigation functions
- Augmented Reality
- Context-awareness apps

The iPhone also has:

- Microphone (noise sensor)
- Proximity sensor
- Ambient light sensor
Introduction: Need for Sensors for the SG

• There is a general consensus that the current power grid is reaching its limitations and that smart-grid technology will be needed to increase efficiency, reliability, and security. The development of such a smart grid presents many new opportunities for the sensors market.

• Sensors will be a key enabler for the smart grid to reach its potential. The idea behind the "smart" grid is that the grid will respond to real-time demand; in order to do this, it will require sensors to provide this "real-time" information.

• The current grid is dominated by a system that is mostly electromechanical in nature, radial in its layout with centralized generating capacity and one way in its communication with little or no sensor feedback to centralized decision makers.

• The transition to a digital network with two-way communication, a network topology with distributed generation, grid storage and pervasive control systems and self monitoring presents extremely attractive opportunities for sensor firms.
Transducers : Sensors, Actuators

• **Sensors** are devices that respond to a physical stimulus heat, light, sound, pressure, magnetism, motion, etc, and convert that into an electrical signal. They perform an input function.

• Devices which perform an output function are generally called **Actuators** and are used to control some external device, for example movement.

• Both **sensors** and **actuators** are collectively known as **Transducers**. Transducers are devices used to convert energy of one kind into energy of another kind.
### Common Transducers

<table>
<thead>
<tr>
<th>Quantity being Measured</th>
<th>Input Device (Sensor)</th>
<th>Output Device (Actuator)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Level</td>
<td>Light Dependant Resistor (LDR) Photodiode Photo-transistor Solar Cell</td>
<td>Lights &amp; Lamps LED's &amp; Displays Fibre Optics</td>
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<td></td>
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<tr>
<td>Temperature</td>
<td>Thermocouple Thermistor Thermostat Resistive temperature detectors (RTD)</td>
<td>Heater Fan</td>
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<tr>
<td>Force/Pressure</td>
<td>Strain Gauge Pressure Switch Load Cells</td>
<td>Lifts &amp; Jacks Electromagnet Vibration</td>
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</tr>
<tr>
<td>Position</td>
<td>Potentiometer Encoders Reflective/Slotted Opto-switch LVDT</td>
<td>Motor Solenoid Panel Meters</td>
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</tr>
<tr>
<td>Speed</td>
<td>Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors</td>
<td>AC and DC Motors Stepper Motor Brake</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound</td>
<td>Carbon Microphone Piezo-electric Crystal</td>
<td>Bell Buzzer Loudspeaker</td>
</tr>
</tbody>
</table>
Types of sensor that are growing (at 35%-50% yr-yr) and are projected to stay there for next 5 years

- **Position sensors** - mobile devices, auto applications, white goods, industrial automation - accel/gyro/magnetometer
- **Pressure /air flow sensors** - the single largest application is automotive TPM (tire pressure monitors) as they are now required in 15 countries, also commercial bldg smart air flow control
- **Motion Sensors** - either IR or proximity based - lighting control
- **Image Sensors** - everything is getting into a camera and image processing
- **Strain Sensors** - this is an insurance and infrastructure item for bldg/bridges/roads/mfg materials, detects wear and service schedule
- **Audio Sensors** - MEMS and Solid state microphones for medical, phones, auto, smart appliances, mobile devices for voice command.
Figure 2: Architecture of a sensor node

- Sensor
- Central Unit (Microprocessor)
- Communication module
  - Battery
  - Memory
  - Queries
  - Data
Sought after Wireless Sensor Attributes

- Adequate Transmission range
- Adequate Battery life
- Provide Secure RF Signal
- Self Locating
- Self Calibrating
- Self Configured
- Self Powered
- Multi-product and Multi-Vendor capability
- Plug & Play capability
- Miniaturization
World Wireless Sensors and Transmitters Market

Technology Segments:
- Temperature
- Pressure
- Level
- Flow
- Acceleration, Vibration
- Humidity
- Gas
- Biosensor
- Photoelectric
- Proximity
- Position

Geographic Segments:
- North America
- Europe
- Asia Pacific
- Rest of World

End-user Segments:
- Industrial Automation
- Aerospace & Defense
- Healthcare, Biometrics
- Building Automation
- Food & Agriculture
- Energy & Power
- Water & Waste Water
- Inventory Control
- Shipping
- Highway & Transportation

Base Year: 2009

Source: Frost & Sullivan
Key challenges for the Wireless Sensor Market

Multivendor equipment interoperability
Demand for industrial-safety-rated wireless devices
Lack of adequate open bandwidth
Deployable network size and hopping challenge
Constantly evolving standards
Wireless Sensor Network (WSN)

• A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location.

• Modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance;

• Today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.
WSN Requirements

• **Large number of sensors**: Networks of 10,000 or even 100,000 nodes are envisioned, so scalability is a major issue.

• **Low energy use**: Since in many applications the sensor nodes will be placed in a remote area, service of a node may not be possible. The lifetime of a node may be determined by the battery life, thereby requiring the minimization of energy expenditure.

• **Network self-organization**: Given the large number of nodes and their potential placement in hostile locations, it is essential that the network be able to self-organize; manual configuration is not feasible. The network must be able to **periodically reconfigure itself** so that it can continue to function.

• **Collaborative signal processing**: The end goal is detection/estimation of some events of interest, not just communications.

• **Querying ability**: An user may want to query an individual node or a group of nodes for information collected in the region. A query may be directed to the sink node nearest to the desired location.
APPLICATIONS OF WSNS

1. Area monitoring
2. Environmental monitoring
   - Greenhouse monitoring
   - Landslide detection
3. Industrial monitoring
   - Machine health monitoring
4. Water/Wastewater monitoring
   - Landfill ground well level monitoring and pump counter
   - Agriculture
5. Fleet monitoring
6. Health Monitoring
7. Security
SMART GRID
A vision for the future — a network of integrated microgrids that can monitor and heal itself.

Smart appliances
Can shut off in response to frequency fluctuations.

Demand management
Use can be shifted to off-peak times to save money.

Solar panels

Houses

Processors
Execute special protection schemes in microseconds.

Sensors
Detect fluctuations and disturbances, and can signal for areas to be isolated.

Storage
Energy generated at off-peak times could be stored in batteries for later use.

Generators
Energy from small generators and solar panels can reduce overall demand on the grid.

Disturbance in the grid

Isolated microgrid

Wind farm

Central power plant

Industrial plant
Sensors for the Smart Grid

• **Basic measurements**: voltage sensing, current sensing, temperature sensing, moisture sensing, continuity sensing and phase measurements.
• **Wireless Sensor Networks for Automated Meter Infrastructure (AMI)**
• **Smart Voltage Sensors**
• **Smart Capacitor Control**, that can monitor and control capacitor banks remotely
• **Smart Sensors for Outage Detection.**
• **Smart Sensors for Transformer Monitoring.**
• **High Voltage Line Temperature and Weather Condition Sensors.**
• **Distributed Generation Sensors** for load balancing
• **Smart Grid Storage** and in load monitoring and dispatch of energy.
Application of WSN to Smart Cities

- Transportation and logistics
- Industrial applications
- Precision agriculture and animal tracking
- Environmental monitoring
- Urban terrain tracking and civil structure monitoring
- Entertainment
- Security and surveillance
- Health care (health monitoring, medical diagnostics)
- Smart grids and energy control systems
- Smart buildings (e.g., indoor climate control)
HAN: Sensors in a Home

Source: “Home Area Network (HAN) Overview”, PG & E, January 2009
Sensors and Sensor Networks used in Smart Home Applications

- Heating, ventilation, and air conditioning systems (HVAC)
- Lightning
- Shading
- Air quality and window control
- Systems switching off devices
- Metering (smart meters)
- Standard household applications (e.g. televisions, washing machines)
- Security and safety (access control).
Different types of Sensors for Smart Buildings

- Temperature sensors and heat detectors
- Light level detectors
- Movement and occupancy sensors
- Smoke and gas detectors
- Status sensors (e.g. air quality, open windows)
- Glass break sensors
## Applications onto Intelligent Transportation Systems

### Intelligent Transportation Systems

#### Intelligent Infrastructure

<table>
<thead>
<tr>
<th>Arterial and Freeway Management</th>
<th>Crash Prevention and Safety</th>
<th>Traffic Incident Management</th>
</tr>
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<tbody>
<tr>
<td>Traffic Signal Control, Lane Management</td>
<td>Warning Systems</td>
<td>Surveillance, Detection</td>
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<tr>
<td>Surveillance, Enforcement</td>
<td>Pedestrian Safety</td>
<td>Response, Clearance</td>
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</tbody>
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<thead>
<tr>
<th>Emergency Management</th>
<th>Electronic Payment and Pricing</th>
<th>Roadway Operations</th>
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<tr>
<td>Hazardous Material Management</td>
<td>Toll Collection</td>
<td>Asset Management</td>
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<tr>
<td>Emergency Medical Services</td>
<td>Multi-Use Payment</td>
<td>Work Zone Management</td>
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<tr>
<th>Transit Management</th>
<th>Traveller Information</th>
<th>Road Weather Information</th>
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<tbody>
<tr>
<td>Operations and Fleet Management</td>
<td>Pre-trip and En-Route Information</td>
<td>Surveillance and Prediction</td>
</tr>
<tr>
<td>Transportation Demand Management</td>
<td>Tourism and Events</td>
<td>Traffic Control</td>
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<tr>
<th>Information Management</th>
<th>Commercial Vehicle Operations</th>
<th>Intermodal Freight</th>
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<tbody>
<tr>
<td>Information Warehousing Services</td>
<td>Carrier Operations, Fleet Management</td>
<td>Freight and Asset Tracking</td>
</tr>
<tr>
<td>Archived Data Management</td>
<td>Credentials Administration</td>
<td>International Border Crossing</td>
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### Intelligent Vehicles

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<thead>
<tr>
<th>Collision Avoidance</th>
<th>Driver Assistance</th>
<th>Collision Notification</th>
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<tbody>
<tr>
<td>Obstacle Detection</td>
<td>Navigation, Route Guidance</td>
<td>Advanced Automated Collision Notification</td>
</tr>
<tr>
<td>Collision-Avoidance Sensor Technologies</td>
<td>On-Board Monitoring</td>
<td>In-Vehicle Crash Sensors</td>
</tr>
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</table>
Parking Lot Sensors: The Smart Santander Project

• This is a new milestone in line with the target for the city of Santander, Spain to become a smart city and improve the quality of life in urban spaces through the use of ICT (Information and Communication Technologies).

• The creation of a network architecture composed of parking sensors, gateways that gather the information sent by the sensor nodes and forward it to some central servers managed by the Smart Santander Project.

• The initiative will involve the design, deployment and validation of a platform composed by 20,000 devices (sensors, actuators, cameras, mobile terminals, etc.) all of them integrated under the umbrella of the so called “Internet of Things”, where every gadget has the ability to communicate to transmit information that is useful to the user (temperature, air pressure, noise level, CO₂ concentration, etc.)

• Once the sensors are installed, the city will continuously monitor parking spaces. The system will report of every change on the occupancy status of the parking spaces.
Applications onto Precision Agriculture

• Sensors and sensor networks are important components of precision agriculture which aims at “maximum production efficiency with minimum environmental impact”.

• Sensors and sensor networks play a critical role in measuring and monitoring the health of the soil and water quality at various stages, from pre- to post-production.

• In precision agriculture, sensor networks can be used for:

  1) plant/crop monitoring, 2) soil monitoring, 3) climate monitoring and iv) insect-disease-weed monitoring.

• Wireless sensors are further used for precision irrigation, and systems developed for remotely controlled, automatic irrigation.

• Finally, sensors are used to assist in precision fertilization. Based on sensor data, decision support systems calculate the “optimal quantity and spread pattern for a fertilizer”.
Sensor Application in Precision Agriculture

150 sensor nodes have been deployed in the field for the experiment. These nodes are equipped with sensors which measure both temperature and relative humidity (see Figure). Additional sensors are deployed in the soil to monitor soil humidity. A weather station “registering the luminosity, air pressure, precipitation, wind strength and direction” (Baggio, 2005) complements the setting.

Sensor nodes send the gathered data via a wireless connection every 10 minutes to field gateways which send it to an ordinary PC for data logging (the Lofar gateway in the figure). The data is further transmitted to other servers for data analysis via a wired Internet connection. A decision support system maps the temperature distribution together with other information. Based on this information, farmers can take different actions and vary the amount of fertilizer and pesticide used.
Summary and Future Work

• This report presented an overview of sensor devices and sensor networks, and their applications on smart grid, and smart cities.

• Sample Smart City application areas included:
  - Smart Homes and Buildings
  - City Transportation, Traffic, Parking
  - Precision Agriculture

• Future Work
  - Data fusion: processing sensor data by filtering, aggregating, and making inferences about the gathered combination of data from multiple sources to obtain improved information: cheaper, greater quality, greater relevance.
  - Self organized/grouping of sensors
  - Node failure, fault tolerant sensor networks
  - Standards: Wireless
For your attention