Chapter 2: Applications

Chapter 2: Roadmap

- Structural Health Monitoring
- Wisden
- Golden Gate Bridge
- Traffic Control
- Kranes
- Aura
- Health Care
- Artificial Retina
- Parkinson Disease
- Pipeline Monitoring
- PaySaft
- Precision Agriculture
- Wine Vineyard
- Litter Agro
- Active Volcano
- Volcán Tungurahua
- Underground Mining

Structural Health Monitoring

- Motivation
  - events:
    - on August 2, 2007, a highway bridge unexpectedly collapsed in Minnesota
    - nine people were killed in the event
    - potential causes: wear and tear, weather, and the weight of a nearby construction project
    - in fact, the BBC reported (August 14, 2007) that China had identified more than 6,000 bridges that were damaged or considered to be dangerous
    - these accidents motivate wireless sensor networks for monitoring bridges and similar structures
Structural Health Monitoring

- Motivation:
  - traditional inspections:
    - visual inspection
      - everyday
    - labor-intensive, tedious, inconsistent, and subjective
  - basic inspections
    - at least once a year
  - detailed inspection
    - at least every five years on selected bridges
  - special inspections
    - according to technical needs
    - the rest require sophisticated tools
      - expensive, bulky, and power consuming

Local and Global Inspections

- Local inspection techniques
  - focus on detecting highly localized, imperceptible fractures in a structure
  - requires:
    - a significant amount of time
    - the disruption of the normal operation of the structure

- Global inspection techniques
  - aim to detect a damage or defect that is large enough to affect the entire structure
  - researcher have been developing and testing wireless sensor networks as global inspection techniques

Wisden

- First prototype to employ WSN for monitoring structural health
  - first deployment
    - for conducting seismic experiments
    - on an imitation of a full-scale 28 x 28 square foot hospital ceiling
    - the overall weight which the ceiling supports is approximately 12,000 pounds
  - second deployment
    - 25 nodes (a tree topology) and a 16 bit vibration card
    - a high-sensitive triaxial accelerometer is attached to the vibration card
    - designed for high-quality, low-power vibration sensing
    - the task of the network was to reliably send time-synchronized vibration data to a remote sink over a multi-hop route
      - NACK
      - hop-by-hop scheme
Golden Gate Bridge (University of California)

64 wireless sensor nodes deployed on this bridge

- The network monitors ambient vibrations synchronously
  - 1 KHz rate, ≤10µs jitter, accuracy=±30µG, over a 46 hop network

- The goal of the deployment:
  - determine the response of the structure to both ambient and extreme conditions
  - compare actual performance to design predictions
  - measure ambient structural accelerations from wind load
  - measure strong shaking from a potential earthquake
  - the installation and the monitoring was conducted without the disruption of the bridge’s operation

Outline

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  - Knaian
  - Arora
- Health Care
  - Artificial Retina
  - Parkinson Disease
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Traffic Control

Motivation:
- ground transportation is a vital and complex socio-economic infrastructure
- it is linked with and provides support for a variety of systems, such as supply-chain, emergency response, and public health
- the 2009 Urban Mobility Report reveals that in 2007, congestion caused urban Americans to
  - travel 4.2 billion hours more
  - purchase an extra 2.8 billion gallons of fuel
- congestion cost is very high - $87.2 billion; an increase of more than 50% over the previous decade

Traffic Control

Motivation:
- building new roads is not a feasible solution for many cities
  - lack of free space
  - high cost of demolition of old roads
- one approach: put in place distributed systems that reduce congestions
  - gather information about the density, sizes, and speed of vehicles on roads
  - infer congestions
  - suggest alternative routes and emergency exits

The Sensing Task

Inductive loops (in-road sensing devices)
- advantages:
  - unaffected by weather
  - provide direct information (few ambiguity)
- how does it work: using Faraday’s induction law
  - a coil of wire (several meters in diameter, passes an electric current through the coil)
  - buried under the road and connected to a roadside control box
  - magnetic field strength can be induced as a result of a current and the speed and the size of passing vehicles
Magnetic Sensors

- Magnetic sensors can determine the **direction** and **speed** of a vehicle
  - a moving vehicle can disturb the distribution of the magnetic field
    - by producing its own magnetic field
    - by cutting across it
  - The magnitude and direction of the disturbance depends on
    - the **speed**, **size**, **density**, and **permeability** of the vehicle

- Classification of magnetic sensors:
  - **low field** (below 1µGauss)
  - **medium field** (between 1µGauss and 10µGauss)
  - **high field** (above 10µGauss)

**Figure 2.2** Detection of a moving vehicle with an ARM magnetic sensor (Caruso and Withanawasam 1999)

Magnetic Sensors

- Almost all road vehicles **contain** a large mass of **steel**
- The magnetic **permeability of steel** is much **higher** than the surrounding air
- **Steel** has the capacity to **concentrate** the **flux lines** of the Earth’s magnetic field
- The **concentration** of magnetic flux **varies as the vehicle moves**; it can be detected from a distance of up to **15m**
- The field variation reveals a **detailed** magnetic signature
- It is possible to distinguish between different types of vehicles
Knaian (2000)

- Proposes wireless sensor networks for traffic monitoring in urban areas
- The node consists of
  - two AMR magnetic sensors to detect vehicular activities
  - by observing the disturbance in the Earth’s magnetic field the vehicular creates
  - the vehicle pulls field lines away from the sensor when it approaches it
  - then towards the sensor when it drives away from it
  - a temperature sensor to monitor road condition (snow, ice, or water)
- To measure the speed of a vehicle, the node waits until it detects an excursion from the predefined baseline and then starts sampling at a frequency of 2KHz
  - two AMR magnetic sensors are placed one at the front of the node and the other at the back - they are shifted in time
  - the node waits for the signal from the rear sensor to cross the baseline
  - then it begins to count the number of samples until the signal from the forward sensor crosses the baseline
  - from this count, it computes the speed of the passing vehicle
Arora et al. (2004)

- Deploys \textit{90 sensor nodes} to detect the movement of vehicles and people (e.g., soldiers)
  - 78 of the nodes were \textit{magnetic sensor nodes} that were deployed in a 60×25 square foot area
  - 12 \textit{radar sensor nodes} were overlaid on the network
- These nodes form a \textit{self-organizing} network which connects itself to a remote computer via a base station and a long haul radio repeater

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- \textbf{Underground Mining}

Health Care

- A wide range of health care applications have been proposed for WSN, including \textit{monitoring patients} with:
  - Parkinson’s Disease and epilepsy
  - heart patients
  - patients rehabilitating from stroke or heart attack
  - elderly people
- Health care applications do \textit{not} function as \textit{standalone} systems
- They are \textit{integral parts} of a comprehensive and complex health and rescue system
Health Care

Motivation:
- **Cost** is very high
  - according to the US Centers for Medicare and Medicaid Services (CMS):
    - the national health spending of the country in 2008 was estimated to be $2.4 trillion USD
    - the costs caused by heart disease and stroke are around $394 billion
  - this is a concern for policy makers, health care providers, hospitals, insurance companies, and patients
- higher spending does not imply quality service or prolonged lifetime (Kulkarni and Öztürk 2007)
  - for example, in 2000, the US spent more on health care than any other country in the world – an average of $4,500 USD per person - but ranked 27th in average life expectancy
- many countries achieve higher life expectancy rates at a lower cost

Motivation:
- Preventive health care - to reduce health spending and mortality rate
  - but some patients find certain practices inconvenient, complicated, and interfering with their daily life (Morris 2007)
  - many miss checkup visits or therapy sessions because of a clash of schedules with established living and working habits, fear of overexertion, or transportation cost

To deal with these problems, researchers proposed comprehensible solutions that involve the following tasks:
- building pervasive systems that provide patients with rich information about diseases and their prevention mechanisms
- seamless integration of health infrastructures with emergency and rescue operations as well as transportation systems
- developing reliable and unobtrusive health monitoring systems that can be worn by patients to reduce the task and presence of medical personnel
- alarming nurses and doctors when medical intervention is necessary
- reducing inconvenient and costly check-up visits by creating reliable links between autonomous health monitoring systems and health institutions
**Commercially Available Sensors**

- Pulse oxygen saturation sensors
- Blood pressure sensors
- Electrocardiogram (ECG)
- Electromyogram (EMG) for measuring muscle activities
- Temperature sensors (core body temperature and skin temperature)
- Respiration sensors
- Blood flow sensors
- Blood oxygen level sensor

**Artificial Retina**

Schwiebert et al. (2001) developed a micro-sensor array that can be implanted in the eye as an artificial retina to assist people with visual impairments

The system consists of an integrated circuit and an array of sensors

An integrated circuit

- Is coated with a biologically inert substance
- Is a multiplexer with on-chip switches and pads to support a 10x10 grid of connections, it operates at 40KHz
- Has an embedded transceiver for wired and wireless communications
- Each connection in the chip interfaces a sensor through an aluminum probe surface

An array of sensors

- Each sensor is a micro-bump, sufficiently small and light
- The distance between adjacent micro-bumps is approximately 70 microns
- The sensors produce electrical signals proportional to the light reflected from an object being perceived
- The ganglia and additional tissues transform the electrical energy into a chemical energy
- The chemical energy is transformed into optical signals and communicated to the brain through the optical nerves
- The magnitude and wave shape of the transformed energy corresponds to the response of a normal retina to light stimulation
Artificial Retina

- The system is a full duplex system, allowing communication in a reverse direction - the sensor array can be used for reception and transmission in a feedback loop
  - in addition to the transformation of electrical signals into optical signals
  - neurological signals from the ganglia can be picked up by the micro-sensors and transmitted out of the sensing system to an external signal processor
- Two types of wireless communications are foreseen

Figure 2.4 The processing components of the artificial retina (Schwiebert et al. 2001)
Parkinson’s Disease

- The aim is to augment or entirely replace a human observer and to help physicians fine-tune medication dosage

- **Weaver (2003)**
  - the system consists of
    - a lightweight sensor node with 3D accelerometer sensors (sampled at a rate of 40Hz.)
    - a processor core
    - a storage system for logging data for later retrieval
    - the system could record 17 hours of accelerometer data
    - the patients wear the nodes in their ankles and wrists
    - the report reveals that the system was able to identify the occurrence of dyskinesia at the rate of 80%

- **Lorincz et al. (2009, Shimmer wireless sensor platform)**
  - The node consists of
    - a TIMSP430 processor
    - CC2420 IEEE 802.15.4 radio
    - triaxial accelerometer
    - rechargeable Lipolymer battery
    - integrates a MicroSD slot (supports flash memory) for storing accelerometer data
  - The node is capable of storing data continuously for more than 80 days, at a sampling frequency of 50Hz

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  - Lutar Agro
- Active Volcanoes
  - Tungurahua
- Underground Mining

- Parkinson’s Disease

- Parkinson’s Disease
Pipeline Monitoring

- **Objective:** monitoring gas, water and oil pipelines
- **Motivation:**
  - management of pipelines presents a formidable challenge
  - long length, high value, high risk
  - difficult access conditions
  - requires continuous and unobtrusive monitoring
  - leakages can occur due to excessive deformations
  - earthquakes
  - landslides or collisions with an external force
  - corrosion, wear, material flaws
  - intentional damage to the structure

To detect leakages, it is vital to understand the characteristics of the substance the pipelines transport

- fluid pipelines generate a hot-spot at the location of the leak
- gas pipelines generate a cold-spot due to the gas pressure relaxation
- fluid travels at a higher propagation velocity in metal pipelines than in a Polyvinyl Chloride (PVC)
- a large number of commercially available sensors to detect and localize thermal anomalies
  - fiber optics sensors
  - temperature sensors and
  - acoustic sensors

PipeNet

- **Motivation:**
  - sewerage systems convey domestic sewage, rainwater runoff, and industrial wastewater to sewerage treatment plants
  - historically, these systems are designed to discharge their content to nearby streams and rivers
  - subsequently, combined sewer overflows are among the major sources of water quality impairment
  - nearly 770 large cities in the US, mainly older communities, have combined sewer systems (Stoianov et al. 2007)
PipeNet

- The PipeNet prototype has been developed to monitor water pipelines in urban areas.

- The task is to monitor:
  - hydraulic and water quality by measuring pressure and pH
  - the water level in combined sewer systems
  - sewer collectors and combined sewer outflows

Three different settings

- First setting:
  - pressure and pH sensors are installed on a 12 inch cast-iron pipe
  - pressure sensor is a modified version of the OEM piezoresistive silicon sensor
  - pressure data is collected every 5 minutes at a rate of 100 Hz for a period of 5s
  - a pH sensor is a glass electrode with an Ag/AgCl reference cell
  - pH data is collected every 5 minute for a period of 10s at a rate of 100 Hz
  - the sensor nodes use a Bluetooth transceiver for wireless communication

Three different settings

- Second setting:
  - a pressure sensor measures the pressure in 8 inch cast iron pipe
  - the data are collected every 5 minutes for a period of 5 s at a sampling rate of 300 Hz.
  - for this setting the raw data was transmitted to a remote gateway
Three different settings

- Third setting:
  - the water level of a combined sewer outflow collector is monitored
  - two pressure transducers (low-power device, < 10 mW) were placed at the bottom of the collector
  - an ultrasonic sensor (high-power device, < 550 mW) was placed on top of the collector
  - efficient power consumption:
    - pressure sensors are employed for periodic monitoring
    - when the difference of pressure sensors and the ultrasonic sensor exceeds a certain threshold; or
    - when the water level exceeds the weir height
    - the ultrasonic sensor is required to verify the readings from the pressure sensors

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Precision Agriculture

- Motivation:
  - traditionally, a large farm is taken as homogeneous field in terms of resource distribution and its response to climate change, weeds, and pests
  - accordingly, farmers administer
    - fertilizers, pesticides, herbicides, and water resources
  - in reality, wide spatial diversity in soil types, nutrient content, and other important factors
  - therefore, treating it as a uniform field can cause
    - inefficient use of resources
    - loss of productivity
  - Precision agriculture is a method of farm management that enables farmers to produce more efficiently through a frugal use of resources
Precision Agriculture

- Precision agriculture technologies:
  - yield monitors
  - yield mapping
  - variable rate fertilizer
  - weed mapping
  - variable spraying
  - topography and boundaries
  - salinity mapping
  - guidance systems

- Requirements of precision agriculture technologies:
  - collect a large amount of data
  - over several days


- Motivation:
  - In a vineyard, temperature is the predominant parameter that affects the quality as well as the quantity of the harvest.
  - Grapes see no real growth until the temperature goes above 10°C.
  - Different grapes have different requirements for heat units.
  - Subsequently, the deployment aims to measure the temperature over a 10°C baseline that a site accumulates over the growing season.

- Beckwith et al. deploy a WSN to monitor and characterize variation in temperature of a wine vineyard.
  - Heat summation and periods of freezing temperatures.
  - 65 nodes in a grid like pattern 10 to 20 meters apart, covering about two acres.
  - Easy to develop the network (1 person day)
    - Due to the self-configuration nature of the network
    - Inherent structured layout of vineyard fields.
  - Two essential constraints of the network topology:
    - Placement of nodes in an area of viticulture interest
    - The support for multi-hop communication.

- The data were used to investigate several aspects:
  - the existence of co-variance between the temperature data collected by the network
  - growing degree day differences
  - potential frost damage
- The mean data enabled to observe the relative differences between heat units accumulation during that period
  - according to the authors' report, the extent of variation in this vineyard – there was a measured difference of over 35% of heat summation units (HSUs) in as little as 100 meters

Lofar Agro (2005)

- WSN at Lofar Agro, the Netherlands
- The network was tasked to monitor phytophthora
  - phytophthora is a fungal disease in a potato field
- Climatological conditions are the main causes of phytophthora
  - monitoring the humidity and temperature conditions in the field
  - monitoring the wetness of the potato leaves
  - determining the potential risk of the disease and the need for fungicides

Lofar Agro (2005)

- Implementation:
  - 150 wireless sensor nodes (heights of 20, 40, and 60 cm)
    - temperature and humidity sensors
  - additional 30 nodes (75 cm) to ensure the network's connectivity
    - the radio range of the nodes reduced when the potato crop was flowering
  - the nodes sampled temperature and humidity at a rate of 1 sample per minute and stored the result temporarily
  - the data were communicated to a remote base station every 10 minutes
Lofar Agro (2005)

- Implementation:
  - delta encoding and periodic sleeping to efficiently utilize energy
    - delta encoding: ten samples were encoded in a single packet
  - the sampled data were logged at a server
  - the server filtered out erroneous readings and handed the accumulated data to the Phytophthora decision support system (DSS) server
  - finally, the decision support system combined the field data with a detailed weather forecast to determine the treatment policy

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Active Volcano

- Volcanoes occur when broken slabs of the Earth’s outermost shell – lithosphere – collide
  - float on the hotter and softer layer in the Earth’s mantle
- Motivation:
  - most of Earth’s volcanoes are hidden from view
  - occurring on the ocean floor along spreading ridges
  - at present, typical active volcanoes are monitored using expensive devices that are difficult to move or require external supply voltage
  - the deployment and maintenance of these devices require vehicle or helicopter assistance
  - data storage must be retrieved on a periodic basis
Active Volcano

- WSNs can be very useful for active volcano monitoring
  - a large number of small, cheap, and self-organizing nodes
  - can be deployed to cover a vast field

- Advantage of WSNs in active volcano monitoring
  - fast and economical deployment
  - possible to achieve high spatial diversity
  - the networks can operate without requiring stringent maintenance routines

Volcán Tungurahua

  - 3 sensor nodes
  - integrate microphones

- Volcán Reventador in northern Ecuador (2005)
  - 16 sensor nodes
  - integrate seism acoustic sensors
  - linear topology (3km)

Volcán Tungurahua

- An important task in active volcano monitoring is to capture discrete events
  - eruptions, earthquakes, or tremor activities
  - these events are transient
  - having duration of less than 60 seconds
  - occurring several times a day

- Therefore, the researchers used the raw data to investigate volcanic activities
  - the samples must be accurately time stamped to allow comparisons between correlated measurements
Volcán Tungurahua

- The sensor architecture consisted of
  - an 8dBi 2.4GHz external omnidirectional antenna
  - a seismometer
  - a microphone
  - a custom hardware interface board
- Operating environment – TinyOS
- Flash memory – for buffering raw data
- Conclusion
  - WSNs are suitable for capturing triggered events
  - WSNs are inadequate for capturing complete waveforms for a long period of time

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Underground Mining

- Motivation:
  - one of the most dangerous work environments in the world
  - Incident of August 3, 2007 at the Crandall Canyon mine, Utah, USA
    - six miners were trapped inside the coal mine
    - their precise location was not known
    - the owners of the mine claimed a natural earthquake was the cause while scientists suspect the mine operations caused seismic spikes
    - a costly and irksome rescue attempt went underway
    - 6.4 cm and 26 cm holes into the mine cavity where drilled, through which
      - an omnidirectional microphone and a video camera were lowered down
    - An air sample was taken – (20% O₂, little CO₂, no CH₄)
Underground Mining

- This evidence caused a mixed anticipation
  - if the miners were alive, the amount of O\textsubscript{2} was sufficient enough to sustain life for some additional days
  - the absence of methane gave hope that there would be no immediate danger of explosion
  - however, the absence of CO\textsubscript{2} and the evidence from the camera and the microphone undermined the expectation of finding the lost persons alive
- More than six labor-intensive days were required to collect the above evidence
- Unfortunately, the rescue mission had to be suspended
  - additional seismic shift in the mountain – this fact strengthened the proposition that man-made causes produced the first incident
- Three rescuers were killed and several were injured

Sources of accidents

- Seismic shifts not the only danger
- Explosions sparked by methane gas and coal-dusts
  - methane from coalification process
  - inadequate ventilation
  - methane from fallen coal
  - methane from the mining faces
  - methane from the walls and ceilings of coal and rock roadways
  - methane from gob of coal mine
- High density coal dust \(\rightarrow\) CO can not disperse into the air \(\rightarrow\) poisonous gas

The Sensing Tasks

- Four tasks:
  - locate individuals
  - locate collapsed holes
  - measure and forecast seismic shifts
  - measure the concentration of gases
- Challenges (extreme hostile environment for radio communication)
  - turns and twists of underground tunnels \(\rightarrow\) impossible to maintain a line-of-sight communication link \(\rightarrow\) signals being highly reflected, refracted, and scattered
  - high percentage of humidity \(\rightarrow\) signal absorption and attenuation is extremely high