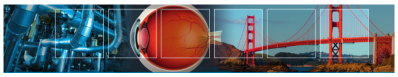
Chapter 2: Applications



Chapter 2: Roadmap

- ***Structural Health Monitoring***
  - ***Wisden***
  - ***Golden Gate Bridge***
- Traffic Control
  - Knaian
  - Arora
- Health Care
  - Artificial Retina
  - Parkinson Disease
- Pipeline Monitoring
  - PipeNet
- Precision Agriculture
  - Wine Vinyard
  - Lofar 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 28×28 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)

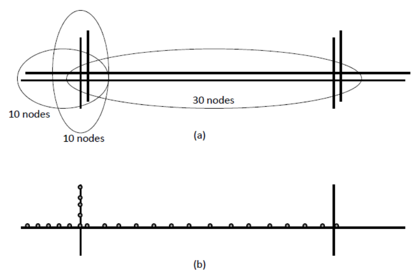


Figure 2.1 The deployment scenario on the Golden Gate Bridge

Golden Gate Bridge

- 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

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Traffic Control

- Motivation:
  - ground transportation is a vital and a *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)

Magnetic Sensors

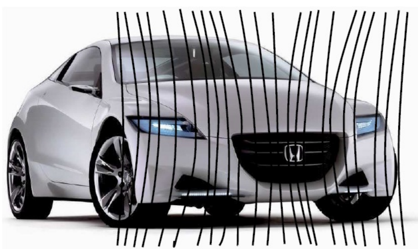

Figure 2.2 Detection of a moving vehicle with an ARM magnetic sensor (Caruso and Withanawasam 1999)

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)

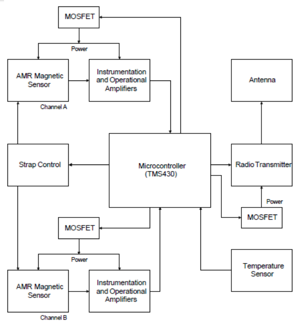

Figure 2.3 Block diagram of the MIT node for traffic monitoring (Knaian 2000)

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)

Knaian (2000)

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

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Health Care

- A wide range of health care applications have been proposed for WSN, including *monitoring patients* with:
  - Parkinson's Disease and epilepsy
  - heart patients
  - patients rehabilitating from stroke or heart attack
  - elderly people
- Health care applications do *not* function as *standalone* systems
- They are *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*

Health Care

- 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*

Health Care

- 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 10×10 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

Artificial Retina

- 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

Artificial Retina

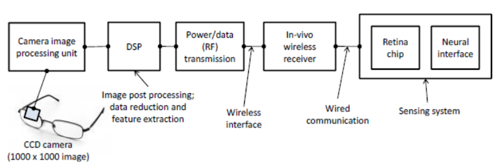

Figure 2.4 The processing components of the artificial retina (Schwiebert et al. 2001)

Artificial Retina

- Figure 2.4 illustrates the signal processing steps of the artificial retina
  - a *camera* embedded in a pair of spectacles *directs its output to* a real-time *DSP*
  - *DSP* - *data reduction and processing*
  - the camera can be combined with a laser pointer for automatic focusing
  - *the output* of the DSP *is compressed* and *transmitted* through a wireless link to the *implanted sensor array*
  - the sensor array decodes the image and produces a corresponding electrical signal

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 latter 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%

Parkinson's Disease

- 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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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

Pipeline Monitoring

- 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

Wine Vinyard (2004)

- 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

Wine Vinyard (2004)

- 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

Wine Vinyard (2004)

- 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 phytophtora*
  - phytophtora is *a fungal disease* in *a potato field*
- *Climatological conditions* are the main causes of phytophtora
  - 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

- Volcán Tungurahua in central Ecuador (2004)
  - 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
- Fash 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***

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% O_2; little CO_2; no CH_4)

Underground Mining

- This evidence caused a mixed anticipation
  - if the miners were alive, the amount of O_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_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 ➔ CO can not disperse into the air ➔ 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 ➔ impossible to maintain a line-of-sight communication link ➔ signals being highly reflected, refracted, and scattered
  - high percentage of humidity ➔ signal absorption and attenuation is extremely high