Sensor Networks for Structural Monitoring: Status, Plans, Problems

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Goal

Designing sensing infrastructure for real-time, high fidelity physical measurement retrieval

Test infrastructure: three story $30' \times 50'$ structure

- Physical phenomenon to be measured:
  - Linear displacement
  - Multi-axial acceleration
  - Structural strain

Linear Displacement Sensing

- Four commonly-used options:
  - Optical tracking
  - Time of flight and triangulation sensors
  - Magnetic, inductive and capacitive sensors
  - Strain gauges and resistive sensors

Linear Displacement Sensing

- Optical tracking
  - Mechanism
    - Markers on the surface
    - Cameras capture mark displacement
    - Image processing calibrated to measure distance
  - Pros
    - Non-contact sensing
    - Simple and safe installation
  - Cons
    - Expensive video capture equipment
    - Difficult calibration
    - High processing requirements
    - High data transfer rates

Linear Displacement Sensing

- Time of flight and triangulation sensors
  - Mechanism
    - Sound or light (laser or IR) waves incident on the surface
    - Measures round trip time or phase shift of the wave to measure distance
  - Pros
    - Laser sensors have high accuracy (up to few microns) and wide measurement ranges (up to few feet)
    - Ultrasonic sensors are safe, most laser sensors in the market are eye-safe
    - Most products usually ship with RS-232 I/O interface
  - Cons
    - Ultrasonic sensors do not have high accuracy and depend on ambient conditions
    - Laser sensors are very expensive ($\approx \$2,000$)
    - Requires 12V DC power supply

Linear Displacement Sensing

- Magnetic, inductive and capacitive sensors
  - Mechanism
    * Magnetic and inductive sensors use the relative movement of a soft iron core and a magnetic field to measure displacements
    * Capacitive sensors measure capacitance changes as distance or overlapping area between conductive plates change
  - Pros
    * These sensors are very cheap
  - Cons
    * Capacitive sensors and some magnetic sensors have a very short range and span of distances
    * Most magnetic and inductive sensors with higher ranges involve the movement of concentric rods (one attached to the moving surface and other to the fixed support)
    * Sensors are affected by ambient conditions like temperature and humidity

Linear Displacement Sensing

- Strain gauges and resistive (potentiometer) sensors
  - Mechanism
    * A shaft in contact with the surface moves, resulting in electrical resistance change which is translated to distance
    * Another design has an extensible chord and a mountable base, whereby pulling the chord results in change of resistance of a potentiometer in the base
  - Pros
    * These sensors are very cheap
    * The chord version can extend up to thousands of inches
    * Essentially the resolution is infinite, however resistance variability may cause inaccuracies
    * Chorded version also allows velocity measurement
  - Cons
    * Involves moving parts implying low life due to wear
    * Need external circuitry and calibration to translate voltage differences to distance
    * Requires 25V supply; variation in input voltage may also cause inaccuracies

Linear Displacement Sensing

- Use of a few laser sensors for high precision measurements and several chorded potentiometers appear to be an attractive option.

- Battery packs can be used to supply power, however the life expectancy of such power packs needs to be evaluated.

- Chorded potentiometers can also be used to evaluate structural strain

Multi-axial acceleration

- 2-*axis* and 3-*axis* accelerometers are available
- Most options have are MEMs devices with small size and low power requirements
- Most common sensors have +/- 2*g* range and with +/- 2 m*g* sensitivity, and are available for only tens of dollars
- Higher end accelerometers are available for a couple of hundred dollars
- Example: MTS420CA is a data acquisition board with 2-*axis* accelerometer, developed by UC Berkeley and Intel and is compatible with MICA2

Network Plan

- For our current test infrastructure both wired and wireless options are possible
- Wireless option allows easier deployment but lower data rates
- For wireless 433 MHz radio communication equipment is available, this allows a maximum of 42 packets per second (12.364 Kbps)
- Using a high number of sensing devices over a large geographical area favors an ad-hoc network of nodes
- Fewer devices in a small area can all directly report to a single master gateway (forming a star topology)

Network Plan: continued..

- MICA2 mote is a good possibility because it also allows programmability and on board processing capability
- For a high density deployment an overlay of gateways with one interface to the mote wireless network and the other to RS-232, Ethernet, or 802.11b can be deployed
- Data streams from the gateways can be redirected via commodity networks to the data sinks possibly over campus networks, WANs, or even the Internet
- Bluetooth communication devices are also an option

Implementation Plan

- In the next few weeks, we must have complete deployment in preparation for tests.
- Set up displacement sensors first – displacement at periphery is adequate at this point.
- Perhaps, start from optical sensing and see if we can use laser rangefinders? (Eyesafe lasers are difficult to scale to larger distances).
- Accelerometers are easy to deploy. These can be done at short notice.

Research and Implementation Issues

- Data rate
- Errors
- Calibrations