Introduction to Embedded Systems

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EECS 124
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Lecture 3: Sensors and Actuators

Sensors and Actuators

Sensors:
- Magnetometers
- Cameras
- Accelerometers
- Rate gyros
- Strain gauges
- Microphones
- Radar/Lidar
- Chemical sensors
- Pressure sensors

Actuators:
- Motor controllers
- Solenoids
- LEDs, lasers
- LCD and plasma displays
- Loudspeakers

Modeling Issues:
- Physical dynamics
- Noise
- Bias
- Sampling
- Interactions

Kingvale Blower
Berkeley PATH Project, March, 2005

Kingvale Blower: Technology Overview
Berkeley PATH Project, March, 2003

Magnetometers

A very common type is the Hall Effect magnetometer.

Charge particles (electrons, 1) flow through a conductor (2) serving as a Hall sensor. Magnets (3) induce a magnetic field (4) that causes the charged particles to accumulate on one side of the Hall sensor, inducing a measurable voltage difference from top to bottom.

The four drawings at the right illustrate electron paths under different current and magnetic field polarities.

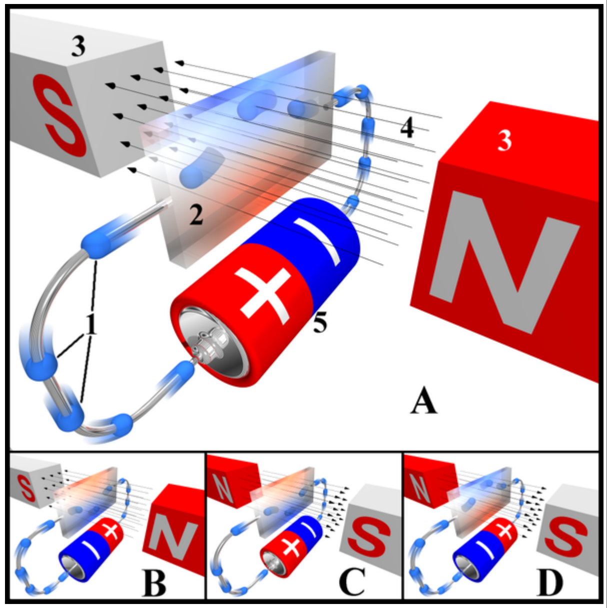


Image source: Wikipedia Commons

Edwin Hall discovered this effect in 1879.

Cameras

- Computer-controlled digital cameras
- Digital video cameras
- Specialized cameras
  - infrared
  - ultra fast/high resolution
  - motion trackers

Pirates of the Caribbean: the Curse of the Black Pearl (2003, Disney) pioneered the use of motion trackers coupled with computer-generated graphics.

At the right: the transformation of Geoffrey Rush
Photo Credit: Industrial Light & Magic.

A Motion-Tracker Facility in Hearst Mining Building

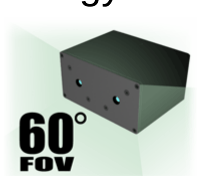
Prof. Ruzena Bajcsy (EECS) maintains a facility that tracks motion of infrared LEDs in 3-D space.

PhaseSpace Motion Capture

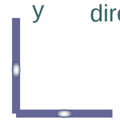
http://www.phasespace.com

Overview of PhaseSpace Motion Tracker Technology

Impulse camera detecting peaks on two linear sensors with 3600 pixels each, arranged in a straight line, each with 60 degree field of view.



Calculation of marker position by correlating the peaks in the x and y directions.



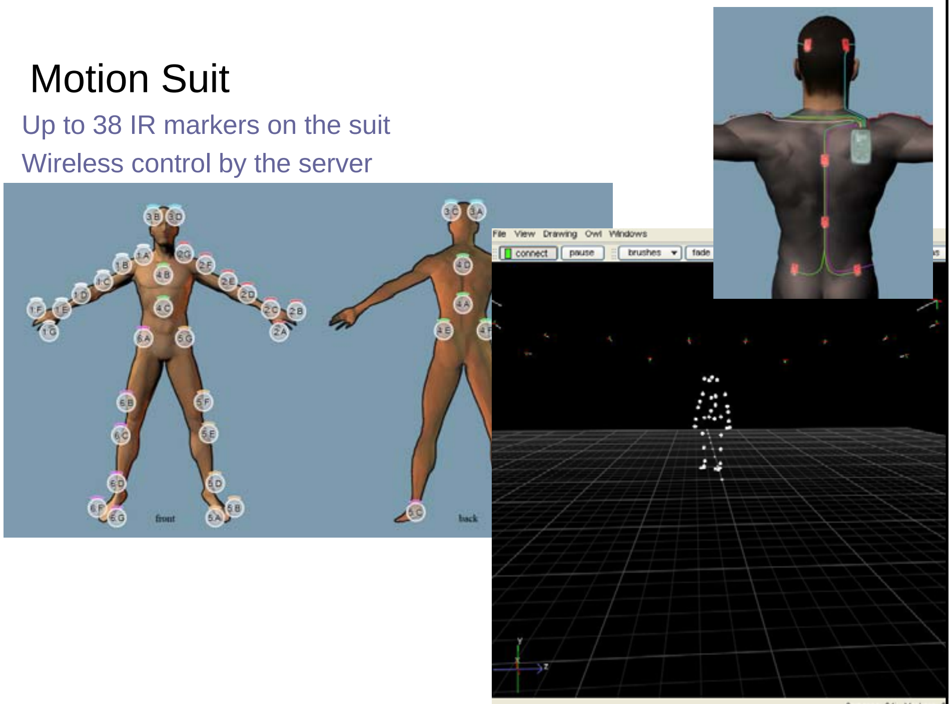
Up to 72 infra-red markers, where each has a unique flashing frequency so that the detector can distinguish them.

Up to 24 cameras can surround the scene

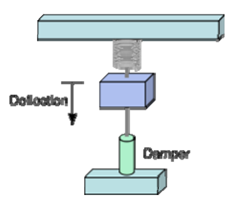
Motion Suit

Up to 38 IR markers on the suit

Wireless control by the server



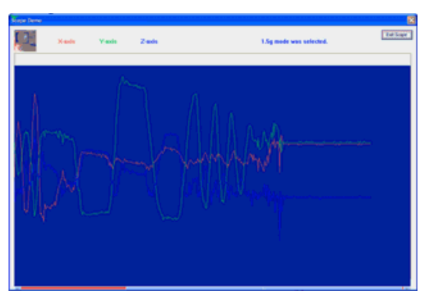
Accelerometers



The most common design measures the distance between a plate fixed to the platform and one attached by a spring and damper. The measurement is typically done by measuring capacitance.

Uses:

- Navigation
- Orientation
- Drop detection
- Image stabilization
- Airbag systems



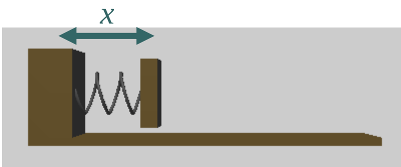
Freescale ZStar is a development kit with a 3-axis accelerometer, wireless link, USB dongle, and demo software.

Spring-Mass-Damper Accelerometer

By Newton's second law, F=ma, gravitational force and acceleration have the same effect (up a scaling constant)

Spring-Mass-Damper System

- mass: M
- spring constant: k
- spring rest position: p
- position of mass: x
- viscous damping constant: c



Force due to spring extension:

$$F_1(t) = k(p - x(t))$$

Force due to viscous damping:

$$F_2(t) = -c\dot{x}(t)$$

Newton's second law:

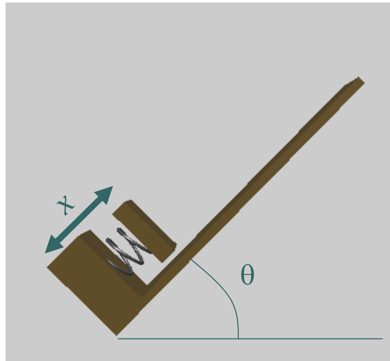
$$F_1(t) + F_2(t) = M\ddot{x}(t)$$

or

$$M\ddot{x}(t) + c\dot{x}(t) + kx(t) = kp.$$

Exercise: Convert to an integral equation with initial conditions.

Measuring tilt



Component of gravitational force in the direction of the accelerometer axis must equal the spring force:

$$Mg\sin(\theta) = k(p - x(t))$$

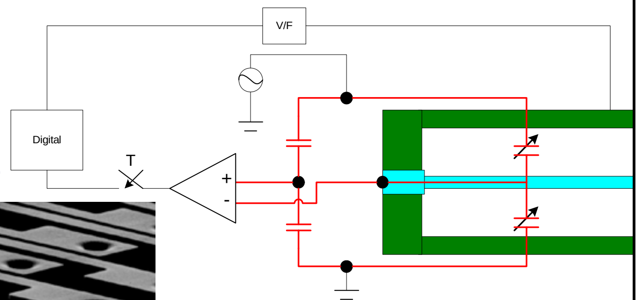
Given a measurement of x, you can solve for θ, up to an ambiguity of π.

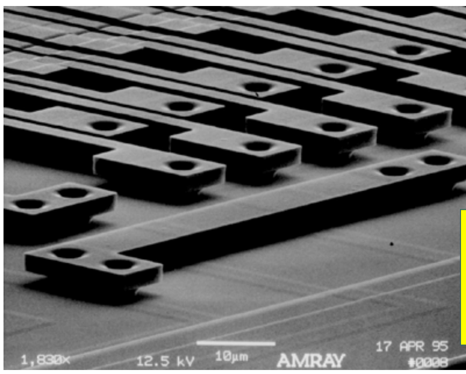
Difficulties Using Accelerometers

- Separating tilt from acceleration
- Integrating twice to get position: Drift
- Vibration
- Nonlinearities in the spring or damper

Feedback dramatically improves accuracy and dynamic range of microaccelerometers.

The Berkeley Sensor and Actuator Center (BSAC) created the first silicon microaccelerometers, MEMS devices now used in airbag systems, computer games, disk drives (drop sensors), etc.

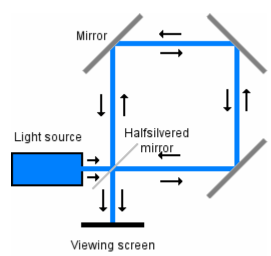




M. A. Lemkin, "Micro Accelerometer Design with Digital Feedback Control",

Ph.D. dissertation, EECS, University of California, Berkeley, Fall 1997

Measuring Changes in Orientation: Gyroscopes



Optical gyros: Leverage the Sagnac effect, where a laser light is sent around a loop in opposite directions and the interference is measured. When the loop is rotating, the distance the light travels in one direction is smaller than the distance in the other. This shows up as a change in the interference.

Images from the Wikipedia Commons

Inertial Navigation Systems

Combinations of:

- GPS (for initialization and periodic correction).
- Three axis gyroscope measures orientation.
- Three axis accelerometer, double integrated for position after correction for orientation.

Typical drift for systems used in aircraft:

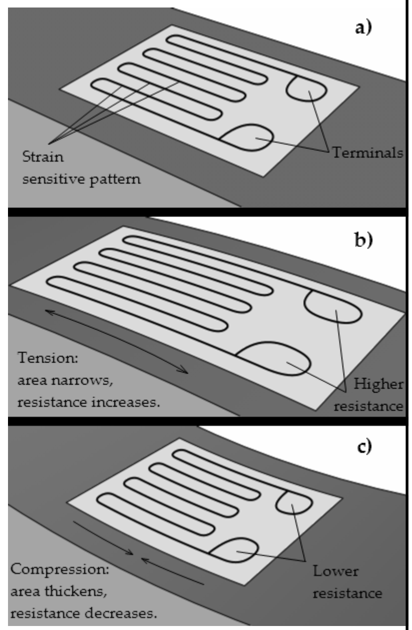
- 0.6 nautical miles per hour
- tenths of a degree per hour

Good enough? It depends on the application!

Browser of the future? (courtesy of Ras Bodik, UCB)

Strain Gauges

Mechanical strain gauge used to measure the growth of a crack in a masonary foundation. This one is installed on the Hudson-Athens Lighthouse. Photo by Roy Smith, used with permission.



Images from the Wikipedia Commons

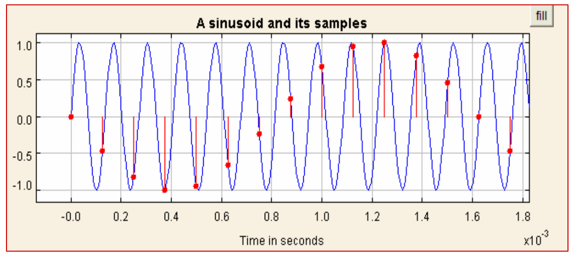
Design Issues with Sensors

- Calibration
  - Relating measurements to the physical phenomenon
  - Can dramatically increase manufacturing costs
- Nonlinearity
  - Measurements may not be proportional to physical phenomenon
  - Correction may be required
  - Feedback can be used to keep operating point in the linear region
- Sampling
  - Aliasing
  - Missed events
- Noise
  - Analog signal conditioning
  - Digital filtering
  - Introduces latency

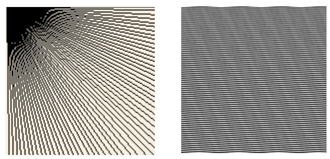
Aliasing

Sampled data is vulnerable to *aliasing*, where high frequency components masquerade as low frequency components.

Careful modeling of the signal sources and analog signal conditioning or digital oversampling are necessary to counter the effect.



A high frequency sinusoid sampled at a low rate looks just like a low frequency sinusoid.



Digitally sampled images are vulnerable to aliasing as well, where patterns and edges appear as a side effect of the sampling. Optical blurring of the image prior to sampling avoids aliasing, since blurring is spatial low-pass filtering.

Noise & Signal Conditioning

Parsevals theorem relates the energy or the power in a signal in the time and frequency domains. For a finite energy signal x, the energy is

$$\int_{-\infty}^{\infty} (x(t))^2 dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} |X(\omega)|^2 d\omega$$

where X is the Fourier transform. If there is a desired part x_d and an undesired part (noise) x_n,

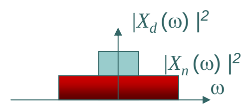
$$x(t) = x_d(t) + x_n(t)$$

then

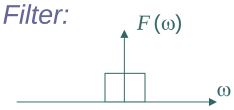
$$X(\omega) = X_d(\omega) + X_n(\omega)$$

Suppose that x_d is a narrowband signal and x_n is a broadband signal. Then the *signal to noise ratio* (SNR) can be greatly improved with filtering.

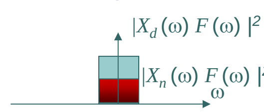
Example:



Filter:



Filtered signal:



A full treatement of this requires random processes.

Motor Controllers

bionicHand.jpg: Photo by Touch Bionics It’s got an embedded computer, a rechargeable battery, and five small dc motors. It costs US $18 500. And it can do things most other prosthetic hands just can’t, like grabbing a paper cup without crushing it, turning a key in a lock, and pressing buttons on a cellphone. The fingers of Touch Bionics’ iLIMB Hand are controlled by the nerve impulses of the user’s arm, and they operate independently, adapting to the shape of whatever they’re grasping. The hand can also do superhuman tricks, like holding a very hot plate or gripping an object tirelessly for days. A skin-tone covering gives the bionic hand a lifelike look, but some customers refer semitransparent models, to proudly flaunt their robotic hands. “They like the Terminator look,” says Touch Bionics CEO Stuart Mead. IEEE Spectrum, Oct. 2007.