The World of Sensors

- The future of computing: a world of embedded processors "intimately connected to the world around them, using sensors and actuators to both monitor and shape their physical surroundings" – D. Tennenhouse, "Proactive Computing", Communications of the ACM, May 2000.
- In fact, most (all?) embedded systems use sensors to detect and measure changes in their environment
  - sensors for position and velocity
  - wireless receiver: responds to electromagnetic radiation
  - pushbutton, or keypad: monitors two states, off and on
  - barcode scanner
  - infrared sensor for stereo remote control
  - handwriting recognition on Palm Pilot
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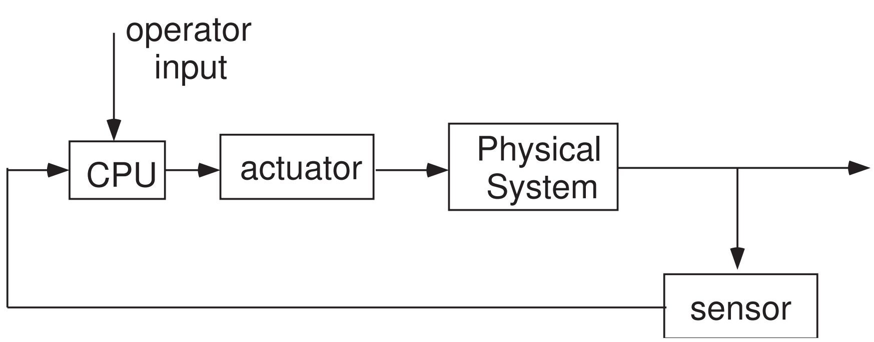
  -
  -
- hundreds or thousands of different sensing technologies. For example, see [1], [2], [3], [5], from which the examples in these notes are taken.

Uses of Sensors

- Monitor changes and report to operator (e.g., turn warning light on)
- Record or process data stream
- Take action: turn something on or off
- Suppose CPU processes sensor signals and uses the result to modify system using an actuator...these modifications are then measured by the sensor



- A *feedback* system

The Future of Sensors

- One of the most rapidly growing areas of technology (see *IEEE Spectrum* and other trade magazines)
- National Science Foundation Engineering Research Center for Wireless Integrated Microsystems (WIMS) located at the University of Michigan
  - Micromachined Vibratory Ring Gyroscope to measure rate or angle of rotation
  - Microaccelerometer to measure micro-g and nano-g accleration, used for inertial navigation, microgravity measurements in space, virtual reality platforms
  - Silicon-probe technology to acquire 3-D images of the electrical activity in the brain
  - poly-diamond strain gauges for cochlear implants
  - environmental sensor arrays to detect pollutants or biological agents
  - Many more: www.wimserc.org

Issues with Sensors

- Physics
  - principles
  - time constants
  - manufacturing tolerances
  - alignment, calibration
- Electronics
  - signal conditioning
  - filtering
  - A/D conversion (explicit or implicit)
    * quantization
    * sampling
  - time constants
- Software
  - latency
  - timing

$\Rightarrow$ Many things that can go wrong! When debugging, must consider all of the above issues...

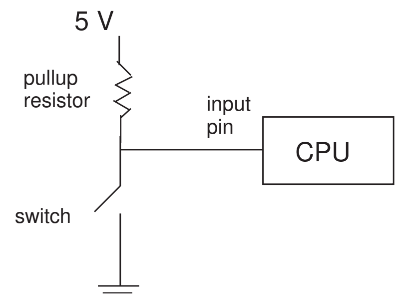
- "Sensors are often rich and elegant examples of engineering principles (mostly analog) in action, and should be introduced into the curriculum in their own right ... else they become receptacles for narrow, digitally conditioned, ideals." – P. Kindlmann, Yale University

An Assortment of Sensors

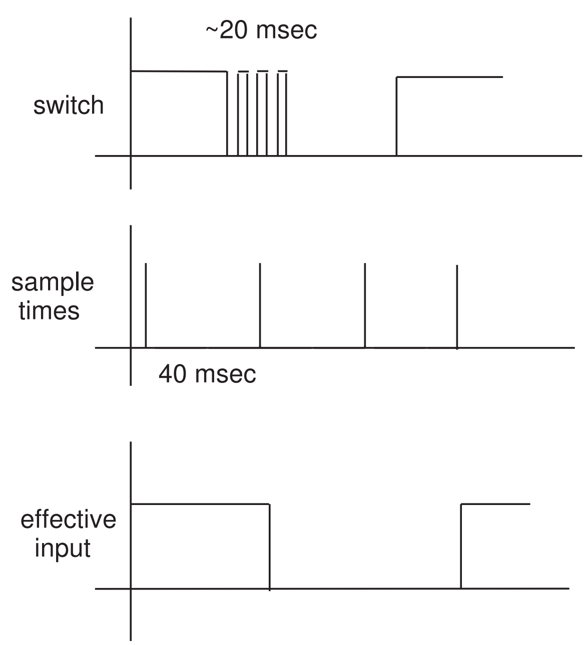
- What variable does the sensor measure?
- What physical principle is used to obtain a measurement?
- Is the sensor analog or digital?
  - Some sensors generate analog signals (voltage, current)
  - Others generate a digital signal directly
- What signal conditioning is required?
- What type of interface electronics are needed?
- What are potential error sources?
  - calibration
  - wear
  - noise
- Programming burden:
  - How rapidly must the sensor be read?
  - Must noise filtering be implemented in software?
- We now explore several sensors used to measure properties of the analog world...

Switch Debouncing

- Small switches or pushbuttons are used to generate an "on" or "off" signal

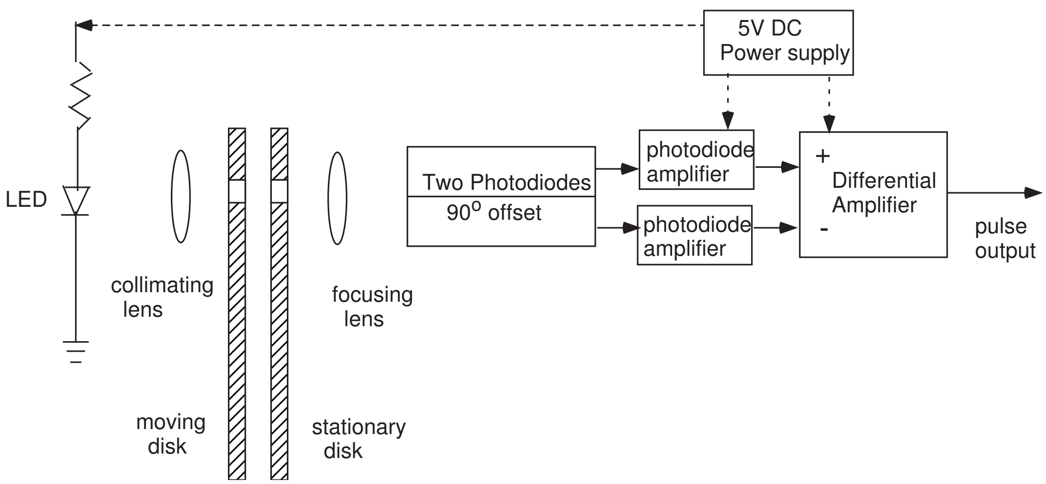


- Problem: When switch is closed, it may "bounce" several times before settling [4], [5].
- The duration of bouncing is short (≈ 20 msec), and is not detectable to a human. However, a microprocessor may respond to these fluctuations, and generate erroneous signals.
- Hardware solution [5]: Add capacitor and Schmitt trigger
- Software solution [5]:



Optical Encoder

- An optical encoder generates a pair of “square wave” signals as windows in the wheel pass over an LED. Details of the mechanism:



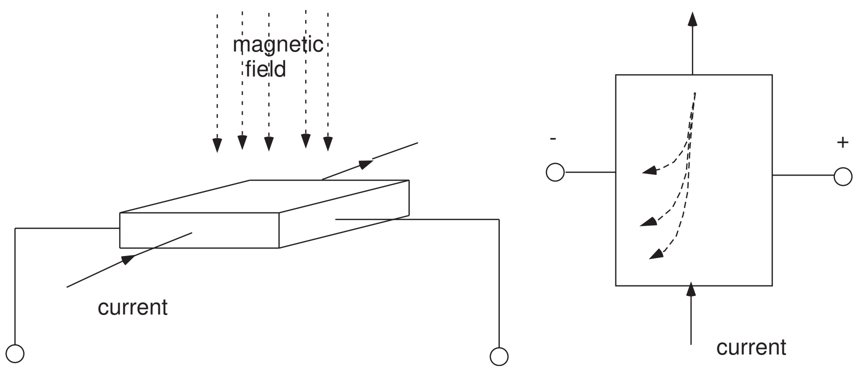
- Two disks are used to allow stronger light source without causing false light reading caused by stray light.
- Two photodiodes for each signal: one is guaranteed to always face opaque area of disk and defines the intensity of the “off” signal. The pulse train is generated based on contrast.
- Potential problems
  - alignment
  - time constants of the photodiodes and electronics
  - manufacturing tolerances
  -

Infrared Remote Detector

- Used in televisions and stereos to detect infrared control signals from a remote.
- Issue: How to prevent the receiver from responding to background radiation (up to 120 Hz), from the sun and from lamps, which has a significant infrared component?
- Solution [5]: Use a “chopper” to modulate the IR light to a high frequency (40 kHz) so that the information content is at a higher frequency than that present in ambient light.

Hall Effect Sensor[1]

- Hall effect: When a magnetic field is applied to a conductor with current flowing through it, a voltage drop across the conductor is generated.

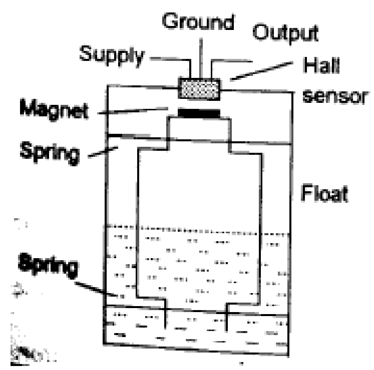


- A sensor that essentially involve detection of a magnet
- Advantages: can be placed in harsh environment, does not involve mechanical contact (no wear, no debouncing)

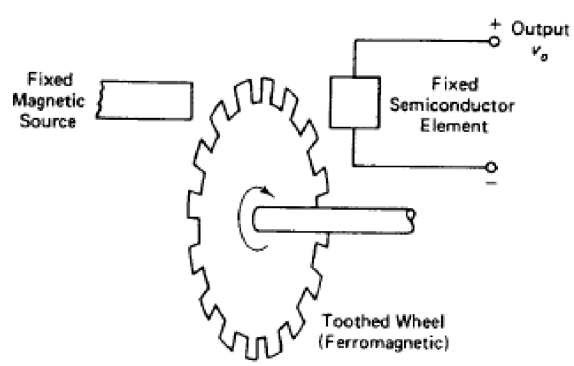
1 [2], [3]

Applications of Hall effect sensors

- analog proximity sensor
- limit switch
- fluid level sensor [2]

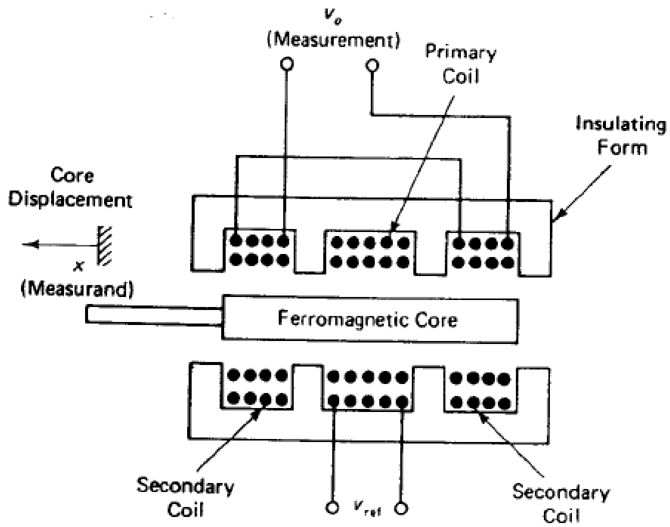


- digital shaft encoder [3]

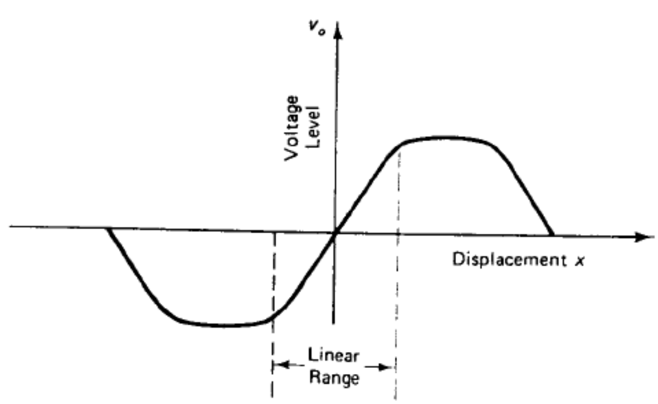


Linear Variable Differential Transformer[2]

- analog position sensor that uses principles of electromagnetism
- advantage over potentiometer: no physical contact required



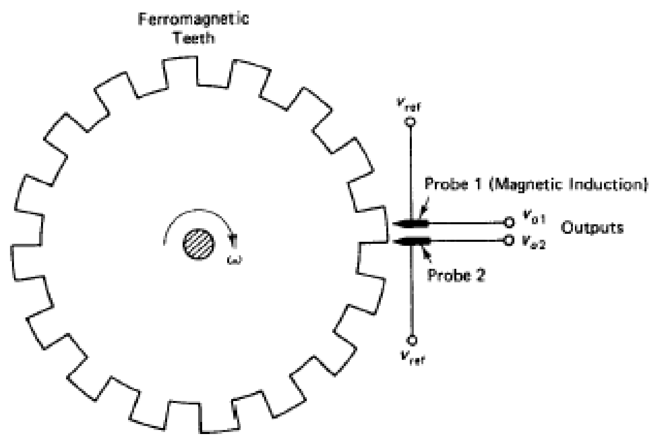
- primary coil driven with AC current
- mutual induction generates AC current in secondary coils
- two secondary coils are connected in series, in opposition, so that when core is centered, net voltage drop is zero
- when core is displaced, voltage drop is nonzero



2 [3]

Pulse Tachometer

- as wheel rotates, a pulse signal is generated that can be used to estimate angular velocity



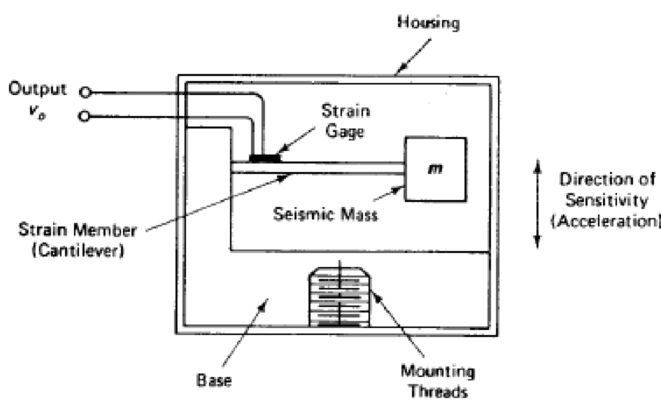
- advantages over optical encoder
  - cost
  - simplicity
  - robustness
- disadvantages over optical encoder
  - poor resolution
  - mechanical errors

Strain Gauge[3]

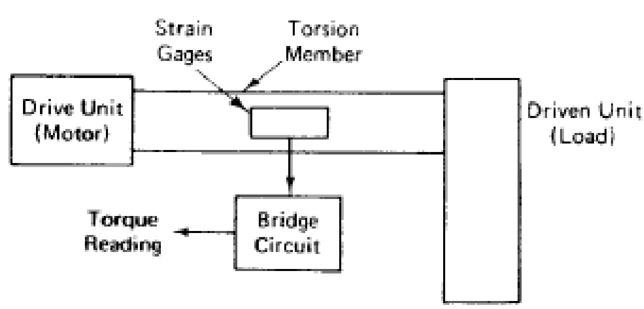
- strain: deformation per unit length
- idea: electrical resistance of material changes when mechanically deformed

$$\Delta R/R = S\Sigma$$

  $\Delta R/R$: relative change in resistance, S: gauge factor, Σ: strain
- metallic foil or semiconductor film attached (postage stamp wise) to material
- strain gauge accelerometer



- strain gauge torque sensor



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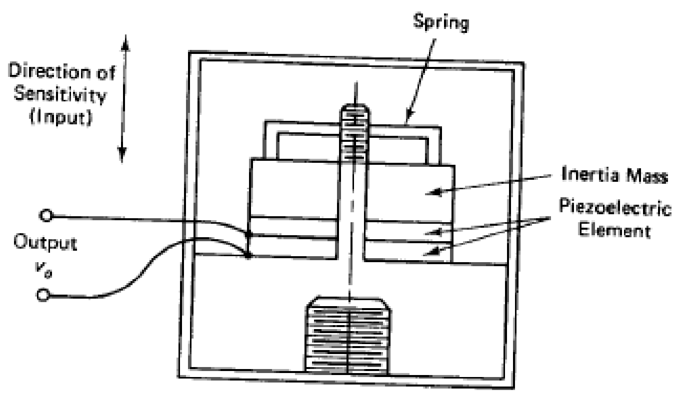
3 [3]

Piezoelectric Sensor[4]

- Certain substances generate an electrical potential when subjected to mechanical stress
- Used directly in pressure sensors, and other sensors such as accelerometers



- Piezoelectric actuator: apply electric potential to cause mechanical deflection

4 [3]

References

References

[1] D. Auslander and C. J. Kempf. *Mechatronics: Mechanical Systems Interfacing*. Prentice-Hall, 1996.

[2] W. Bolton. *Mechatronics: Electronic Control Systems in Mechanical and Elecrical Engineering, 2nd ed.* Longman, 1999.

[3] C. W. deSilva. *Control Sensors and Actuators*. Prentice Hall, 1989.

[4] R. Grehan, R. Moote, and I. Cyliax. *Real-Time Programming: A Guide to 32-bit Embedded Development*. Addison-Wesley, 1998.

[5] T. W. Schultz. *C and the 8051, Volume II: Hardware, Modular Programming, and Multitasking*. Prentice-Hall, 1999.