Robot Sensors

Dr. Rohan Munasinghe
Department of Electronic and Telecommunication Engineering
University of Moratuwa

- Allow a robot to interact with its environment in a flexible, and intelligent manner
  - In contrast to preprogrammed operations (in an overwhelming majority of industrial applications)
- A robot that can see and feel is much easier to train and deploy to perform complex tasks
  - Adaptable to much wider variety of tasks
Robot sensor taxonomy

- **Internal sensors**
  - Position sensor
  - Velocity sensors
  - Torque and acceleration sensors

- **External sensors**
  - Tactile sensors
  - Force and torques sensors
  - Proximity sensors
  - Range sensors
  - Vision sensors
  - Others
Internal sensors
- Provide position, velocity, and acceleration as a continuous stream of feedback signals that possess an integral part of the control loop.

External sensors
- Provide information about the environment and the objects therein (for collision avoidance, etc.).
- Don’t come with the basic package. Can be bought and installed as optional sensors.

Sensor Characteristics

- Dynamic range
  - Minimum and maximum values of the input signal for which the sensor responds
- Response
  - Sensor should respond to the stimuli almost instantaneously
- Sensitivity
  - The change in sensor output for a unit change in input
- Linearity
  - Whether the sensor maintains same sensitivity within the entire dynamic range
- Other considerations
  - Sensor should not disturb the physical quantity it measures
  - Sensor should be suitable for the environment it is exposed
  - Sensor should be isolated from noise, and protected from physical damages
  - Size, cost, and ease of operation
Position Encoding

- Potentiometer
- Optical shaft encoder

Absolute Encoder

Parallel Data

No initialization needed
Relative Position, Direction of motion, and Initial Position

When the joint is brought to a home position, the z-phase pulse is generated for initializing the up-down counter.

Distinguishing clockwise and counter-clockwise rotations

Track A

Track B

Clockwise rotation

Counter-clockwise rotation

Track A is 90 degrees ahead of track B.

Track A is 90 degrees behind.

Phase ⇒ Direction of motion
Pulse count (and derivative) ⇒ position (and velocity)
Velocity Measurement Using an Encoder

Velocity \approx \text{Pulse Frequency}

The drawback of pulse frequency measurement

As the angular velocity gets slower, only a few pulses are observed in the fixed time interval:

discretization error increases.

A better alternative is to measure the interval between adjacent pulses $t_{\text{int}}$, and take the reciprocal for estimating the velocity.

$$\omega \propto \frac{1}{t_{\text{int}}}$$
Hybrid velocity counter

Measuring the time interval between adjacent pulses:
More accurate in slower speed

Indicates whether or not a contact has been made, while disregarding the magnitude of the contact force

Micro switches, limit switches

Counting the number of pulses in a fixed time interval:
More accurate in higher speed

Touch sensor

- Indicates whether or not a contact has been made, while disregarding the magnitude of the contact force
  - Micro switches, limit switches
Tactile array

- Matrix of force sensing elements
  - Presence of the object
  - Pressure distribution
  - Object shape, and orientation
  - Slipping information

Tactile Sensors

Tactile Pad

Electrodes

Conductive Rubber:
Media impregnated with conductive dopants

Other Methods:
- Capacitive
- Optical
- Piezoelectric
- Magneto-resistive
- Magneto-elastic

Force/Pressure $P$

Resistance $R$

-force/pressure $P$
For grasping, assembly tasks where control of contact force is essential

Wrist attachment is the most common
**Proximity Sensor**

- LED
- Photo Detector

- **Electrostatic sonar** transducer
- 0.9~35ft, 50~60kHz
- Emits ultrasonic ping and listen to the echo
  
  time of flight \( \times 0.5 \times \) sound speed = distance to obstacle

- **Problems**
  - False echoes
  - Sound speed changes on temperature and humidity

- **Receiving gain** = \( \frac{1}{vt^4} \)

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**Ultrasonic Range Sensor**

- **Electrostatic sonar** transducer
- 0.9~35ft, 50~60kHz
- Emits ultrasonic ping and listen to the echo
  
  time of flight \( \times 0.5 \times \) sound speed = distance to obstacle

- **Problems**
  - False echoes
  - Sound speed changes on temperature and humidity

- **Receiving gain** = \( \frac{1}{vt^4} \)
- Internal resonances take 2.38ms to decay out. It is only after that echoes can be detected (min distance limit)

- At a distance, echo becomes too weak to be detected (max distance)

As frequency increases:
- beamwidth reduces
- attenuation increases

Beamwidth shouldn’t be too wide to hear false echoes. It shouldn’t be too narrow to miss a legitimate obstacle

Narrow beamwidth sensor + mechanical scanning.

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F = d_{33} \cdot q
\]

(Voltage) = proportional to (Displacement)