Introduction to Computer Vision and Robotics

Robotic Sensors

Mohamad Javad Aein
WS 2014-2015
Modeling
Kinematics
Dynamic

Sensing
Actuation
Motion Planning
AI

Control
Modeling

Kinematics

Dynamic

Control

Sensing

Actuation
Today!
What is a sensor?

Transducer

Input energy  ➔  Output energy

Sensor

Input energy  ➔  Electrical energy

Thermocouple (Analogue Sensor)

Varying voltage ➔  Signal Conditioner or System ➔  Analogue Output Signal

Liquid

Heat

Analogue Signal ➔  Time

Output Signal
What is a sensor?

Input energy → Transducer → Output energy

Electrical → Actuator → Output energy
Why do we need sensors?
Why do we need sensors?

Uncertainty in actuator

Uncertainty in Environment
Why do we need sensors?
Why do we need sensors?

Sensor: detects events or changes in quantities
Types of sensors

Proprioception (PC)
Types of sensors

- Proprioception (PC)
- Motor speed
- Heading
- Joint torque
- Battery status
Types of sensors

- Proprioception (PC)
  - Motor speed
  - Heading
  - Joint torque
  - Battery status

- Exteroception (EC)
Types of sensors

Proprioception (PC)
- Motor speed
- Heading
- Joint torque
- Battery status

Exteroception (EC)
- Distance to objects
- Ext. Force/torque
- Light intensity
- Tactile sensor
Types of sensors

Thermistor
Types of sensors

Thermistor

Passive
Types of sensors

Thermistor

Ultrasonic sensor

Passive

9V BATTERY SNAP
PRESET RESISTOR
THERMISTOR
NPN TRANSISTOR
6V RELAY

Sender/Receiver

Object

reflected wave

original wave
distance r
Types of sensors

Thermistor

Passive

Ultrasonic sensor

Active
Sensor characteristics

- Range and Span
- Resolution
- Accuracy
- Precision
- Dead zone
Sensor characteristics

Range and Span

Resolution

Accuracy

Precision

Dead zone

Range

Minimum and Maximum value

e.g.: Temperature range -40 to 70

Span

Difference of Max and Min values

e.g.: span 110 degrees
Sensor characteristics

Range and Span

Resolution

Accuracy

Precision

Dead zone

Resolution

Minimum detectable change in input

e.g: Temperature range 0.1 degree

e.g: 0.1 % of span
Sensor characteristics

- Range and Span
- Resolution
- Accuracy
- Precision
- Dead zone

**Accuracy**

Difference between output and true value

- e.g: Temperature accuracy 0.5 degree
- e.g: 1 % of span
Sensor characteristics

- Range and Span
- Resolution
- Accuracy
- Precision
- Dead zone

Resolution vs Accuracy

- Increased Resolution
- Increased Accuracy
Sensor characteristics

- **Range and Span**
- **Resolution**
- **Accuracy**
- **Precision**
- **Dead zone**

**Precision**

Repeatability of measurement

- e.g: Temperature precision 0.1 degree
- e.g: 0.2 % of span
Sensor characteristics

**Range and Span**

**Resolution**

**Accuracy**

**Precision**

**Dead zone**

**Precision vs Accuracy**

Not precise: Bad sensor!

Not accurate: calibration!
Sensor characteristics

- Range and Span
- Resolution
- Accuracy
- Precision
- Dead zone

Precision vs Accuracy

Not precise: Bad sensor!

Not accurate: calibration!
Proprioception
- Position/Velocity
- Heading
- Wheel speed

Exteroception
- Position/Velocity
- Heading
- Obstacles
Classes of sensors

Motor/Axis sensor

Potentiometer

- wiper turns with dial
- resistive material
Classes of sensors

Motor/Axis sensor

Potentiometer

Absolute position!

Cheap
Low performance
Classes of sensors

Motor/Axis sensor

Resolver
Classes of sensors

Motor/Axis sensor

Incremental encoder
Classes of sensors

Motor/Axis sensor

Incremental encoder

Example: 1000 pulse/turn

\[ \alpha = 360 \text{ deg} \times \frac{1000}{1000} = 0.36 \text{ deg} \]

amplitude

\[ \omega = \frac{\alpha}{t} \]

direction

<table>
<thead>
<tr>
<th>Current Value</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
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<td>+</td>
<td>-</td>
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<tr>
<td>2</td>
<td>-1</td>
<td>X</td>
<td>0</td>
<td>+1</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>+1</td>
<td>-1</td>
<td>0</td>
</tr>
</tbody>
</table>
Classes of sensors

Motor/Axis sensor
Incremental encoder

Speed
No absolute position!

Example: 1000 pulse/turn

\[ \omega = \frac{\alpha}{t} \]

\[ \alpha = 360^\text{deg} \frac{1000}{1000} = 0.36^\text{deg} \]
Motor/Axis sensor  
Absolute encoder  

### Classes of sensors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Contact 1</th>
<th>Contact 2</th>
<th>Contact 3</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>off</td>
<td>off</td>
<td>off</td>
<td>0° to 45°</td>
</tr>
<tr>
<td>1</td>
<td>off</td>
<td>off</td>
<td>ON</td>
<td>45° to 90°</td>
</tr>
<tr>
<td>2</td>
<td>off</td>
<td>ON</td>
<td>off</td>
<td>90° to 135°</td>
</tr>
<tr>
<td>3</td>
<td>off</td>
<td>ON</td>
<td>ON</td>
<td>135° to 180°</td>
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<tr>
<td>4</td>
<td>ON</td>
<td>off</td>
<td>off</td>
<td>180° to 225°</td>
</tr>
<tr>
<td>5</td>
<td>ON</td>
<td>off</td>
<td>ON</td>
<td>225° to 270°</td>
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<tr>
<td>6</td>
<td>ON</td>
<td>ON</td>
<td>off</td>
<td>270° to 315°</td>
</tr>
<tr>
<td>7</td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
<td>315° to 360°</td>
</tr>
</tbody>
</table>
Classes of sensors

Motor/Axis sensor

Absolute encoder

Gray code

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<thead>
<tr>
<th>Sector</th>
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<tbody>
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</tr>
</tbody>
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Normal binary
Classes of sensors

Motor/Axis sensor

Potentiometer

Resolver

Incremental encoder

Absolute encoder

NEW!

Inductive encoder (Incoder)
Classes of sensors

Heading sensors

- Compass
  - Earth magnetic field
    - Noisy
    - Sensitive to roll and pitch
    - Together with accelerometer

- Mechanical
- Hall effect
- Magneto resistive
Mechanical

Hall effect

Magneto resistive
Classes of sensors

Heading sensors

inclinometer

Measuring the tilting angle by means of the electric conductance

Figure 2: Nomenclatures of the new design of PEOPLER-II.

Figure 12: The prototype of the PEOPLER-II.
Classes of sensors

Positioning

GPS

Global positioning system

Electromagnetic wave (speed of light)
Position and velocity

expensive

Only outdoors

Next: Indoor Positioning System (IPS)
Mechanical wave (speed of sound)
Position and velocity

Local
Classes of sensors

Positioning

Retroreflective beacon
Inertial navigation system (INS)

Gyroscope

Accelerometer

Inertial measurement unit (IMU)
Classes of sensors

- Gyroscope
- Angular rate sensor

Mechanical

Precession
Classes of sensors

Gyroscope

Angular rate sensor

Measuring Angular Velocity
Classes of sensors

Gyroscope

Angular rate sensor

Sagnac effect

 Optical Gyroscope

Ring laser

Fiber optic

\[ t_1 = \frac{2\pi R}{c - R\omega}, \]

\[ t_2 = \frac{2\pi R}{c + R\omega}. \]
Classes of sensors

Gyroscope

Angular rate sensor

Vibrating Gyroscope
Classes of sensors

Accelerometer

Acceleration sensor

Mass-Spring system
Inertial navigation system (INS)

- Gyros
- Accelerometers

INS

Inputs:
- $\omega_{ib}^b$
- $f^b$

Outputs:
- Velocity: $v^t$
- Attitude: $R^b_i$
- Horizontal position: $R^l_e$
- Depth: $z$

Processing:
- Rate-gyroscope signals
- Accelerometer signals

Orientation: Project accelerations onto global axes
Correct for gravity
Initial Velocity
Initial Position
Global Accel
Velocity
Position
<table>
<thead>
<tr>
<th>Proprioception</th>
<th>Exteroception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position/Velocity</td>
<td>Position/Velocity</td>
</tr>
<tr>
<td>Heading</td>
<td>Heading</td>
</tr>
<tr>
<td>Wheel speed</td>
<td>Obstacles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Joint Position</th>
<th>Ext. Force/Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Velocity</td>
<td>Grasp (Fingertips)</td>
</tr>
<tr>
<td>Joint Torque</td>
<td>Obstacles</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>Range/Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obstacles</td>
</tr>
</tbody>
</table>
Classes of sensors

- Range/Proximity
- Bumper sensor

Diagram showing a bumper sensor with components labeled as:
- Hinged bumper
- Microswitch
- Rod (linear movement)
Classes of sensors

Range/Proximity

Infrared
Classes of sensors

Range/Proximity

Laser range finder

Measure distance from observer to target

Time of Flight (ToF)
Classes of sensors

Range/Proximity

Ultrasonic range finder

SONAR: sound navigation and ranging

Basic sonar illustration – a transducer generates a sound pulse and then listens for the echo.
Classes of sensors

Range/Proximity

- magnetic range finder
- Inductive
- Hall effect
- Camera
Classes of sensors

Tactile sensors

Pressure array

Tactel (tactile element)

Capacitive sensor

Piezoelectric
Classes of sensors

**Force/Torque**

**Torque sensor**

- Strain gauge #1
- Strain gauge #2

FORCE

Bridge unbalanced
Classes of sensors

Force/Torque

6 DOF F/T

ATI Nano25 F/T Sensor
Overview

- What is a sensor
- Why do we need sensors?
- Types of sensors
- Sensor characteristics
- Classes of sensors
Artificial Intelligence Robotics: An Introduction
Poramate Manoonpong & Frank Hesse (Uni. Göttingen, WS2013/2014)
CH2_2
Fundamental Physical Components of Robots
Aim of this Course: How to develop "Intelligent Robots"

Fundamental Physical Components
(Body, Sensors, Actuators)
Aim of this Course: How to develop "Intelligent Robots"

Fundamental Physical Components
(Body, Sensors, Actuators)

Actuators & Body
Why Actuators?
Why Actuators?

- Otherwise our robots will be indistinguishable from passive objects like this:
Actuators
Actuators

- Motors
- Hydraulic/Pneumatic Actuators
- Artificial Muscles
- Inflatable Robot/Actuators
- Omnidirectional Wheels
Motors

• Direct current (DC) considered, since battery driven systems
Motors

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- Motor design:
  - Standard DC
  - Stepper Motors
  - Servo Motors
Motors

• Direct current (DC) considered, since battery driven systems

• Motor design:
  – Standard DC
  – Stepper Motors
  – Servo Motors

• Adjustment of speed and direction of motion
DC Motor – Principle
DC Motor – Principle

- An electric current in a magnetic field will experience a force.

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – Principle

- An electric current in a magnetic field will experience a force.

- Wire bent into a loop, then the two sides of the wire with right angles to the magnetic field will experience forces in the opposite direction.

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothrow.html
DC Motor – Principle

- The forces create a turning influence or torque to rotate the coil

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – Principle

- The forces create a turning influence or torque to rotate the coil

- Practical motors have several loops (in the armature) to provide a more uniform torque

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – Principle

- Torque produced by motor: $\tau_m = K_m i$
  - $K_m$ torque constant of motor, $i$ current in armature, generated by the voltage $V_a$ applied to the motor
DC Motor – Principle

• Torque produced by motor: \( \tau_m = K_m i \)
  \( K_m \) torque constant of motor, \( i \) current in armature, generated by the voltage \( V_a \) applied to the motor

• Output power: \( P_o = \tau_a \omega \)
  \( \tau_a \) applied (required) torque, \( \omega \) angular velocity of axis

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  - \( \tau_a \) applied (required) torque, \( \omega \) angular velocity of axis
- Input power: \( P_i = V_a i \)
  - \( V_a \) applied voltage, \( i \) current in armature
- Efficiency: \( \eta = \frac{P_o}{P_i} = \frac{\tau_a \omega}{V_a i} \) (not constant for all speeds)

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor

- Possibility to change the direction of motion

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – H-Bridge

- Possibility to change the direction of motion

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DC Motor – H-Bridge

- Possibility to change the direction of motion

[Diagram showing connections and components of a H-Bridge circuit]

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – H-Bridge

- Possibility to change the direction of motion
- Close either switches 1 and 4

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – H-Bridge

- Possibility to change the direction of motion
- Close either switches 1 and 4, or 2 and 3 to run motor forward/backward, respectively

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – Pulse Width Modulation (PWM)

- So far motor either runs or not
- Control of speed also necessary

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DC Motor – Pulse Width Modulation (PWM)

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- Control of speed also necessary
  - Analogue circuitry providing desired voltage, hence regulating speed
  - PWM: pulses of full system voltage (e.g. 5V) at fixed frequency (e.g. 20 kHz) generated by microcontroller
    - Varying pulse width changes effective analog motor signal and hence controls the speed (motor behaves like integrator for certain time span)
    - $\frac{t_{on}}{t_{period}}$ called pulse-width ratio or duty cycle

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motor – Step Motor

http://pcbheaven.com/wikipages/How_Stepper_Motors_Work/
DC Motor – Step Motor

- So far motors rotate freely
- Step motors allow to rotate for a given number of degrees (property of motor and control mode)
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DC Motor – Step Motor

- So far motors rotate freely
- Step motors allow to rotate for a given number of degrees (property of motor and control mode)

- 4 coils with 90° angle between each other (fixed on the stator)
- Direction/step width of shaft is determined by order in which coils are activated

http://pcbheaven.com/wikipages/How_Stepper_Motors_Work/
DC Motor – Step Motor

Wave drive or Single-Coil Excitation

- One coil is energized each time
- Rarely used, generally when power saving is necessary
- Less than half of the nominal torque of the motor, therefore the motor load cannot be high

http://pcbheaven.com/wikipages/How_Stepper_Motors_Work/
DC Motor – Step Motor

Full step drive
• Coils are energized in pairs
• Most often used
• According to connection of coils (series or parallel) motor will require double voltage or double current to operate (compared to Single-Coil Excitation) and produces 100% of the nominal torque of the motor.

http://pcbheaven.com/wikipages/How_Stepper_Motors_Work/
DC Motor – Step Motor

Half stepping
- Double accuracy of positioning system, without change in hardware
- All coil pairs can be energized simultaneously, causing the rotor to rotate half the way as a normal step.
- Can be single-coil or two-coil excitation as well

http://pcbheaven.com/wikipages/How_Stepper_Motors_Work/
DC Motor – Step Motor

**Microstepping**

- Coils are powered with waveform similar to a sine (also digitized)
- Most common method to control stepper motors nowadays
- Smoother positioning
- Single-coil excitation and full step drive possible
- Motors $\sim 1^\circ$ step width available

http://pcbheaven.com/wikipages/How_Stepper_Motors_Work/
DC Motor – Servo Motor
DC Motor – Servo Motor
DC Motor – Servo Motor

- DC motor with encapsulated gearbox and electronics for PW control of desired (angular) position
- ~ ±120° around center position
DC Motor – Servo Motor

- DC motor with encapsulated gearbox and electronics for PW control of desired (angular) position
- \(~\pm120^\circ\) around center position
- 3 wires
  - \(V_{cc}\)
  - Ground
  - PW input
- Board compares desired position with current position obtained from potentiometer
- Speed cannot be set, goes to new position as fast as possible
DC Motor – Servo Motor

- DC motor with encapsulated gearbox and electronics for PW control of desired (angular) position
- ~ +/-120° around center position
- PWM signal for control:
DC Motors – In General

Remember:
• No (externally available) sensor attached to motor
• Wheel encoders have to be attached additionally

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
DC Motors – In General

Remember:

- No (externally available) sensor attached to motor
- Wheel encoders have to be attached additionally

Criteria for motor selection:

- Task (servo/step/normal motor)
- Provides enough torque and speed
- Weight
- Size
- Efficiency $\eta$

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
Other Actuators

- Hydraulic/Pneumatic Actuators
- Artificial Muscles
- Inflatable Robot/Actuators
- Omnidirectional Wheels

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html
Hydraulic/Pneumatic Actuators

- Single- and double-acting cylinders

![Diagram of single- and double-acting cylinders](image)

- External force causes retraction
- Vented to atmosphere
- Pressurized fluid flow
- Low-pressure fluid flow
- Extension
- Retraction
- Single-acting
- Double-acting
Hydraulic/Pneumatic Actuators

- Single-acting cylinders exert force either on extension or retraction
- They require an outside force to complete the second motion
- Double-acting cylinders generate force during both extension and retraction
Hydraulic/Pneumatic Actuators

- Also hydraulic rotation actuators

http://www.youtube.com/watch?v=U4KpMiXOUAI
Artificial Muscles

- Can be used with air or fluid
Artificial Muscles

- Humanoid with fluid muscles

www.youtube.com/watch?v=pgKBWkY3Qks
Inflatable Robot

Inflatable Robot

- Pneumatic hand

http://www.youtube.com/watch?v=BUtBd4sVrzA
Omnidirectional Wheels

- Wheel with additional small discs around the circumference
- Normal forward movement
- Slide laterally with great ease
Omnidirectional Wheels

• Robot with omnidirectional wheels

http://youtu.be/XmEuu9X6s1E
Omnidirectional Wheels

- Fork lifter with omnidirectional wheels

http://youtu.be/CjcyHicm3NA
Actuators – Summary

• Principle of DC motors
• Other actuators:
  • Hydraulic/Pneumatic Actuators
  • Artificial Muscles
  • Inflatable Robot/Actuators
  • Omnidirectional Wheels
  • ...

‡