Lecture 4: Kinesthetic haptic devices: Sensors and Actuators

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a kinesthetic haptic system
sensors
sensor types

• magnetic
  - magnetic: TrakStar, Ascension

• optical
  - optical: Microsoft Kinect
  - optical: Polaris, NDI

• acoustic
  - acoustic: ultrasonic proximity sensor, BiF

• inertial
  - inertial: wearable IMU, MotionNode

• mechanical
  (our focus, since these are the sensors typically integrated with the actuator in kinesthetic haptic devices)
  - mechanical: Faro arm
mechanical trackers

• ground-based linkages most commonly used

• joint position sensors
  – digital: optical encoders are most common
  – analog: magnetic sensors and potentiometers are most common
optical encoders

- how do they work?
  - A focused beam of light aimed at a matched photodetector is interrupted periodically by a coded pattern on a disk
  - Produces a number of pulses per revolution (Lots of pulses = high cost)

- quantization problems at low speeds

- absolute vs. referential
optical encoders

• phase-quadrature encoder

• 2 channels, 90° out of phase
  – allows sensing of direction of rotation
  – 4-fold increase in resolution
magnetoresistive angle sensors

- magnetoresistive materials change their electrical resistance when an external magnetic field is applied

- the resistance depends on the angle between the magnetization vector of the ferromagnetic material and the direction of current flow (resistance is largest if they are parallel)

- often 4 sensors are connected in a Wheatstone bridge configuration (similar to strain gages)
potentiometers

Analog input pin → potentiometer

Diagram showing electrical circuitry with a potentiometer and voltage sources.
measuring velocity

• differentiate position
  – advantage: use same sensor as position sensor
  – disadvantage: get noisy signal

• alternative
  – for encoders, measure time between ticks
discrete differentiation

• many different methods

• simple example:
  – average 20 readings = P1
  – average next 20 readings = P2
  – where $t$ is the period of the servo loop

• differentiation increases noise

• usually need to filter

\[ V = \frac{P1 - P2}{t} \]
position/velocity filtering

- one example is the simple infinite impulse response filter

```
// Return RC low-pass filter output samples, given input samples,
// time interval dt, and time constant RC
function lowpass(real[0..n] x, real dt, real RC)
    var real[0..n] y
    var real α := dt / (RC + dt)
    y[0] := x[0]
    for i from 1 to n
        y[i] := α * x[i] + (1-α) * y[i-1]
    return y
```

- pseudocode for real-time filtering:
  new_value = read_from_sensor()
  filtered_value = a*new_value + (1-a)*old_value
  old_value = filtered_value
time-between-ticks

- encoders fare poorly at slow velocities
  - there may be very few ticks during a single servo loop
- instead, some specialized data acquisition boards use a special chip that measures time between ticks
  - fares poorly at high velocities

\[ v = \frac{\Delta p}{\Delta t} \]
discussion

what are the advantages/disadvantages for haptics of the three sensor types discussed (optical encoders, magnetoresistive angle sensors, and potentiometers)?

are there any common types of sensors you find missing from this discussion?
actuators
actuator types

![Diagram showing actuators types based on power/weight ratio and weight. Shape Memory Metals at low power/weight ratio and low weight. Pneumatic Actuators and Hydraulic Actuators have higher power/weight ratios and weight compared to dc Motors.]
PM DC brushed motors

• rotating *armature* with coil windings is caused to rotate relative to a permanent magnet

• current is transmitted through brushes to armature, and is constantly switched so that the armature magnetic field remains fixed.
DC motor components
DC motor terms

- **cogging/torque ripple**
  - tendency for torque output to ripple as the brushes transfer power

- **friction/damping**
  - caused by bearings, brushes, and eddy currents

- **stall torque**
  - max torque delivered by motor when operated continuously without cooling
torque ripple

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<th>commutator segments</th>
<th>commut. points</th>
<th>torque ripple</th>
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<td>26</td>
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http://www.maxonmotorusa.com/
motor equations

- torque constant $\tau = k_T i$
- speed constant $v_{\text{emf}} = k_v \dot{q}$

- dynamic equations

\[ v = L \frac{di}{dt} + Ri + v_{\text{emf}} \]

\[ m\ddot{q} + b\dot{q} = \tau \]
motor amplifier types

**current amplifier**
(voltage controlled current source VCCS)

directly controls current
current = torque (good!)
expensive

**voltage amplifier**
(voltage controlled voltage source VCVS)

indirectly controls current
current depends on ???
less expensive (???)

![Circuit diagram](image)

Vin

[+]

OPA544

[-]

DC motor

2 Ohm

Circuit board design by Louis Whitcomb, JHU

ardumotor shield
https://www.sparkfun.com/products/9815
based on L298 H-bridge
pulse width modulation

assumes that the average signal is a constant signal

duty cycle is the proportion of on time to the period

useful if you do not have a D/A converter to send analog signals to the motor circuit
switching frequency must be much faster than the mechanical dynamics of the system
transmission

• Transfers/amplifies force/torque from motor

• You don’t want to feel or see the effects of the transmission!

• Types:
  – gears
  – belts/pulleys
  – capstan drive
  – none (direct drive)
capstan drive

high transmitted force, low transmitted friction
capstan drive

a version of the haptic paddle

Phantom Premium, SensAble Technologies
direct drive

motors attached directly to link(s)

Hayward (McGill)
Haptics Demos

Go to **MERL 126** to feel haptics demos, including:
Virtual environment with Phantom Omni/Geomagic Touch
Virtual environment with Force Dimension Omega
Bilateral teleoperation with Phantom Premium

Tue: 11:20 – 11:50 am   Last names A-J
Thu: 11:20 – 11:50 am   Last names K-Z