Lecture 3: Kinesthetic haptic devices: Sensors and Actuators

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pay lab materials fee
$50 check made out to Stanford University, by class time Thursday 9/18

bring your laptop w/USB on Thursday
so you can test communication with the Hapkit Board

do Assignment #1
http://web.stanford.edu/class/me327/#c3
do your 3D printing as early as possible!

two optional seminars this week
  Wednesday @ 1:30 pm MER 203, Friday @ 12:30 pm @ Gates B1
  see details on piazza
Office Hours for this week

- Allison: Tuesday (today) 4:30-6 pm in 520-145
- Nathan: Wednesday (tomorrow) 3-5 pm in 520-145
- Jake: Wednesday (tomorrow) 5-6 pm in 520-145

- 520-145 (D'Arbeloff Teaching Lab) schedule is online
- You can also post questions to piazza
- You can also email us for an appointment (please email all three of us and be sure to state your available times for the next couple of days)
sensors
sensor types

- magnetic
- optical
- acoustic
- inertial

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

magnetic: TrakStar, Ascension
optical: Polaris, NDI
optical: Microsoft Kinect
acoustic: ultrasonic proximity sensor, BiF
inertial: wearable IMU, MotionNode
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)
Hall-Effect Sensors

How do they work?

a small transverse voltage is generated across a current-carrying conductor in the presence of a magnetic field

(Discovery made in 1879, but not useful until the advent of semiconductor technology.)
Hall-Effect Sensors

\[ V_h = \frac{R_h IB}{t} \]

- amount of voltage output related to the strength of magnetic field passing through.
- linear over small range of motion (need to be calibrated)
- affected by temperature, other magnetic objects in the environments

\[ V_h = \text{Hall voltage} \]
\[ R_h = \text{Hall coefficient} \]
\[ I = \text{Current} \]
\[ B = \text{Magnetic flux density} \]
\[ t = \text{Element thickness} \]
potentiometers
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

\[ V = \frac{P1 - P2}{t} \]

• differentiation increases noise

• usually need to filter
position/velocity filtering

• one example is the simple infinite impulse response filter

```cpp
// 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
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

![Graph showing torque ripple with commutator segments and rotation angle. The graph includes a table with commutator segments, commutator points, and torque ripple values.](http://www.maxonmotorusa.com/)

<table>
<thead>
<tr>
<th>commutator segments</th>
<th>commut. points</th>
<th>torque ripple</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10</td>
<td>5 %</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>14 %</td>
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<td>7</td>
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<td>1 %</td>
</tr>
<tr>
<td>13</td>
<td>26</td>
<td>0.75 %</td>
</tr>
</tbody>
</table>
motor equations

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

- dynamic equations
  \[ v = L \frac{di}{dt} + Ri + v_{emf} \]
  \[ m \ddot{q} + b \dot{q} = \tau \]
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 board design by Louis Whitcomb, JHU

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

http://www.barrgroup.com/

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

- DC motor with encoder
- Capstan drive
- Axis of rotation
- Load cell
- Thermal insulator

a version of the haptic paddle

Phantom Premium, SensAble Technologies
direct drive

motors attached directly to link(s)

Hayward (McGill)