Lecture 15:
Teleoperation: Implementation

Allison M. Okamura
Stanford University
teleoperation history and examples
the genesis of teleoperation?

a Polygraph is a mechanical device that produces a copy of a piece of writing simultaneously with the creation of the original, using pens and ink. Famously used by Thomas Jefferson ~1805.

Typically uses a pantograph mechanism: a five-bar linkage with parallel bars such that motion at one point is reproduced at another point.
teleoperation history

• first telemanipulator: 1948, Ray Goertz, U.S. Atomic Energy Commission
  – goal was to protect workers from radiation, while enabling precise manipulation of materials
  – a device which is responsive to another device is called the “follower” and the controlling device is termed a “master”

• at first, mechanical linkages and cables

• 1954: electrical and hydraulic servomechanisms

• 1960s: closed-circuit television and head-mounted displays (HMDs)
bilateral control = force feedback

• inherent in “mechanical” teleoperators
• forces at the follower end-effector are reflected to the master end-effector
• displacements produced at the follower end-effector produce a displacement at the master end-effector
modern telemanipulators

• undersea: exploration and oil acquisition

• space

  – 1967: Surveyor III landed on the surface of the Moon (a few seconds delay in the two-way transmission to earth of commands and information)

  – 1976: Viking spacecraft, landed on Mars was programmed to carry out strictly automated operations

  – Shuttle Remote Manipulator System (SRMS): retrieves satellites and place them in the cargo bay; mobile work platform for astronauts during space walks
even more dexterous teleoperation

• Robonaut
  – Robot Systems Technology Branch at NASA's Johnson Space Center
  – purpose is to replace astronauts in dangerous missions, such as space walk, on the space shuttle and/or the space station
  – both autonomous operation and teleoperation are being developed
surgical robotics
(e.g., da Vinci Surgical System)
simple system example

Abbott and Okamura 2004
teleoperation
controllers
unilateral teleoperator model
bilateral teleoperator model (using position)
bilateral teleoperator model (using force)

teleoperation block diagrams
typical follower robot controller

this is a proportional-derivative controller, which attempts to make the follower (2) follow the master (1) position and velocity

\[ f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2) \]

- \( f_{a2}(t) \): follower actuator force
- \( x_1 \): position of master
- \( x_2 \): position of follower
- \( k_{p2} \): follower proportional gain
- \( k_{d2} \): follower derivative gain

for each “haptic loop” the master’s position is recorded and the follower robot attempts to follow the master.
master robot controller for unilateral teleoperation

\[ f_{a1}(t) = 0 \]

\[ f_{a1}(t) \] master actuator force

the force applied by the master actuator (if it exists) is zero
master robot controller for bilateral teleoperation (using position)

\[ f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1) \]

- \( f_{a1}(t) \) master actuator force
- \( x_1 \) position of master
- \( x_2 \) position of follower
- \( k_{p1} \) master proportional gain
- \( k_{d1} \) master derivative gain

for each “haptic loop,” the follower’s motion is recorded and the master robot attempts to follow the follower
master robot controller for bilateral teleoperation (using force)

\[ f_{a1}(t) = f_e \]

- \( f_{a1}(t) \): master actuator force
- \( f_e \): measured environment force

for each “haptic loop,” the force between the follower and the environment is measured, and the master robot outputs this amount of force
implementation summary

**follower robot controller**

\[ f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2) \]

**unilateral teleoperation:**

\[ f_{a1}(t) = 0 \]

**master robot controller**

**bilateral teleoperation (position-exchange):**

\[ f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1) \]

**bilateral teleoperation (position forward, force feedback):**

\[ f_{a1}(t) = f_e \]
Teleoperation
Setup with Hapkits
hapkit example
### Implementation Summary

**Follower Robot Controller**

\[ f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2) \]

**Master Robot Controller**

**Unilateral Teleoperation:**

\[ f_{a1}(t) = 0 \]

**Bilateral Teleoperation (Position-Exchange):**

\[ f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1) \]

**Bilateral Teleoperation (Position Forward, Force Feedback):**

\[ f_{a1}(t) = f_e \]
Suggestions

• Connect both motors to one Hapkit Board. Call the Hapkit with this board the “master”.

• Connect the MR sensor on the “follower” Hapkit Board to an analog input on the “master”.

• Duplicate all functions in code to include “follower” Hapkit (sections previously do not edit)

• The “follower” MR sensor still needs power!

• Add a common ground between Hapkits!

• Duplicate all functions in code to include “follower” Hapkit.
<table>
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<tr>
<th>ATmega 328 chip pin #</th>
<th>ATmega 328 pin name</th>
<th>Typical Arduino function</th>
<th>Special Hapkit function</th>
<th>Pin name printed on Hapkit Board</th>
<th>Pin number to use in Arduino program</th>
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<td>Reset</td>
<td>Reset</td>
<td>RST</td>
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<td>2</td>
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<td>Digital Pin 0 (RX)</td>
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<td>Digital Pin 1 (TX)</td>
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<td>SD card Slave Select Line</td>
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<td>9</td>
<td>PB6 (PCINT6/XTAL1/TOSC1)</td>
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<td>PD6 (PCINT22/OC0A/AIN0)</td>
<td>Digital Pin 6 (PWM)</td>
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<td>PD7 (PCINT23/AIN1)</td>
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<td>21</td>
<td>AREF</td>
<td>Analog Reference</td>
<td>AREF</td>
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<td>GND</td>
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<td>Analog Input 5</td>
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