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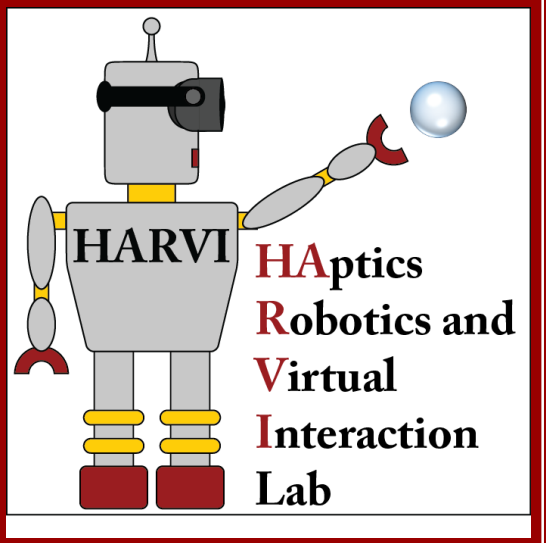


HAPTICS

DR. HEATHER CULBERTSON
UNIVERSITY OF SOUTHERN CALIFORNIA

- hearing
- sight
- smell
- taste
- touch

- What sense is most valuable to you?
- Which sense would you relinquish last?

DEFINITION: HAPTIC

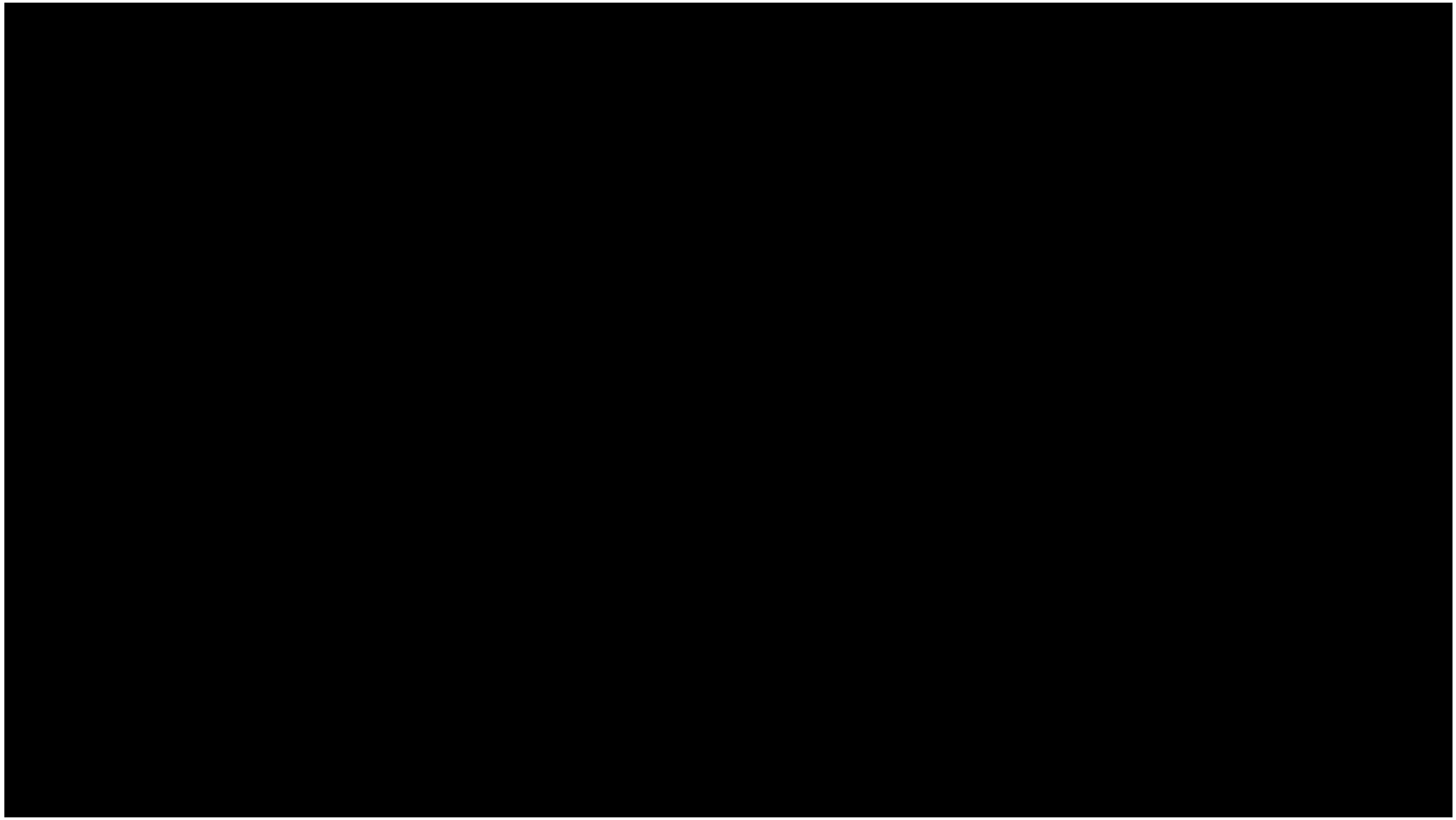
› adj. Of or relating to the sense of touch [Greek haptikos, from haptesthai, to grasp, touch. (1890)]

Kinesthesia:
Location/configuration
Motion
Force
Compliance

Cutaneous/Tactile:
Temperature
Texture
Slip
Vibration
Force

The haptic senses work together with the motor control system to:
- Coordinate movement
- Enable perception

WHAT WOULD LIFE BE LIKE WITHOUT TOUCH?



https://www.youtube.com/watch?v=0LfJ3M3Kn80

WHAT IS THE EVOLUTIONARY PURPOSE OF HAPTICS?

- What does common sense say?
- Not sure what you just came up with, but my summary is:
  - Evaluation: know what is good and what is bad
  - Manipulation: climb trees, use tools
- Research (sort of) supports this:
  - Density of RA afferents (which are found only in glabrous skin) correlates with fruit consumption; possibly also with arboreal living

Hoffmann, Joscelyn N., Anthony G. Montag, and Nathaniel J. Dominy. "Meissner corpuscles and somatosensory acuity: the prehensile appendages of primates and elephants." *The Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology* 281.1 (2004): 1138-1147.

HOW YOUR COMPUTER SEES YOU

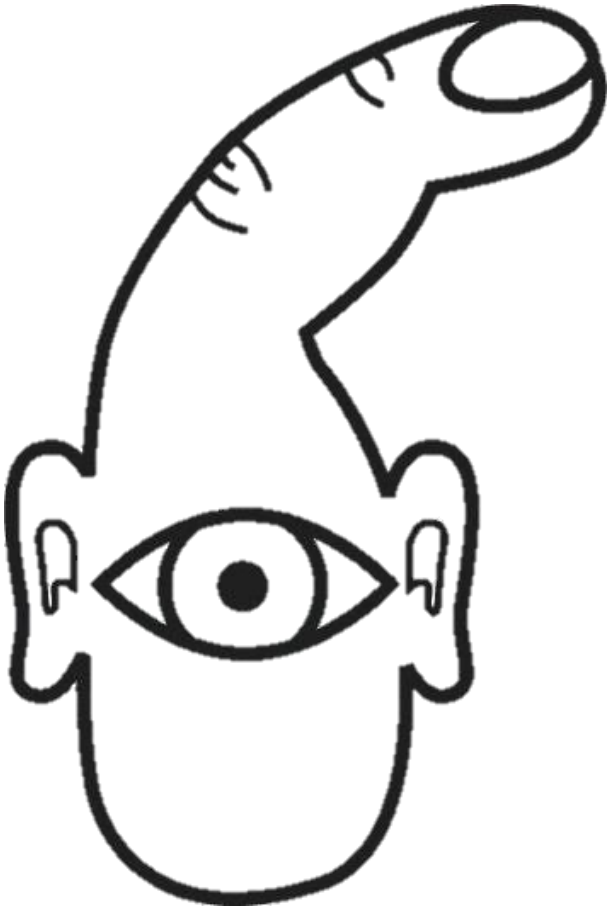
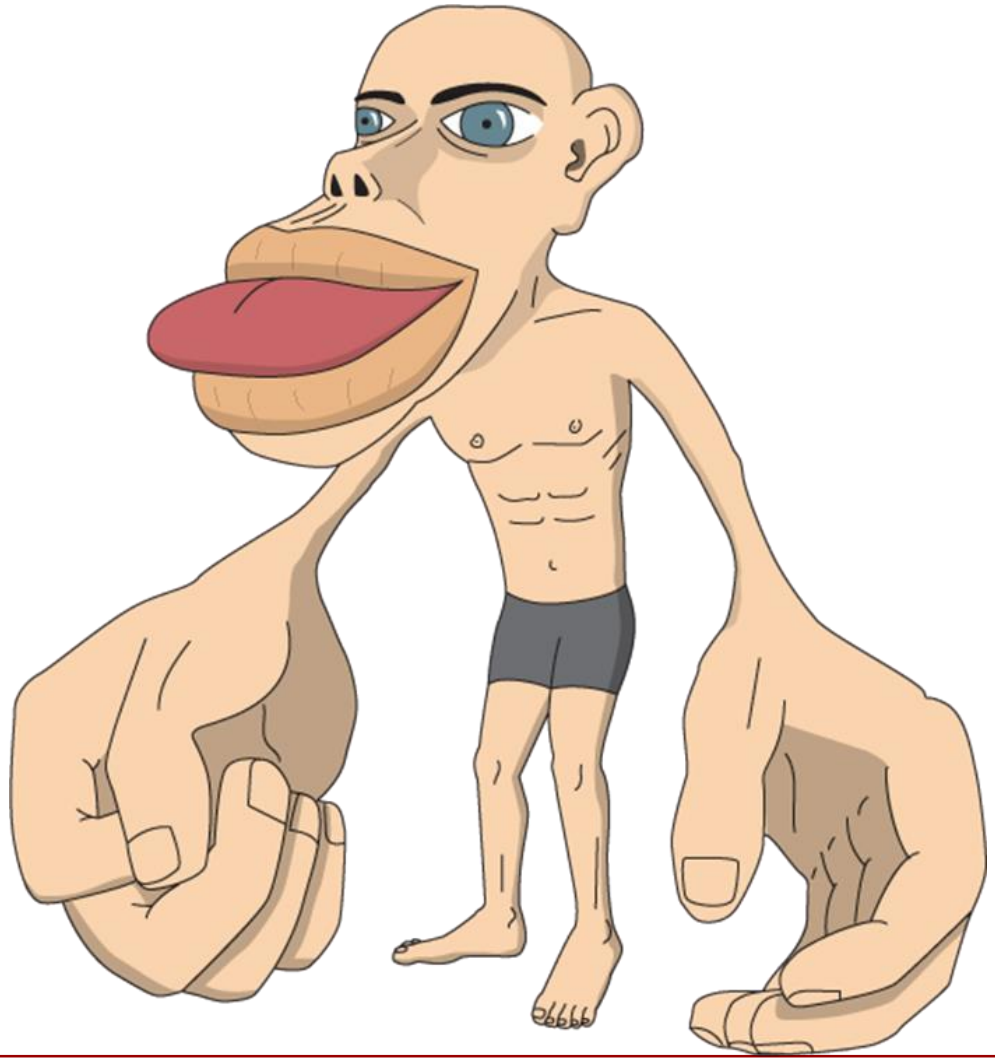


illustration by Tom Igoe

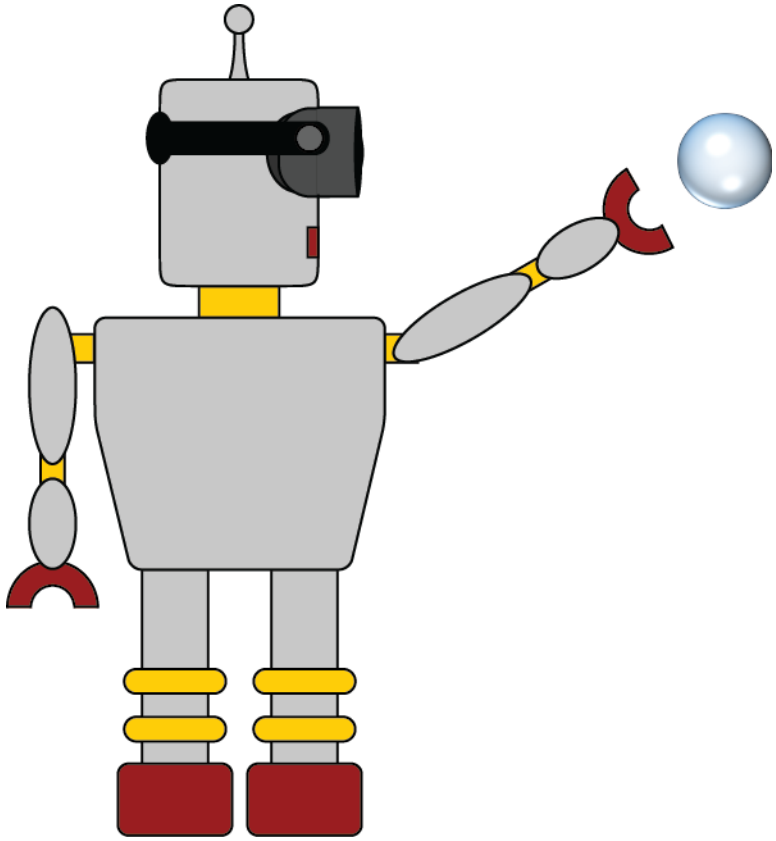
HOW YOUR SENSES ARE REALLY DISTRIBUTED



HAPTIC DEVICES

HAPTICS:

› Touch-based interaction between an intelligent agent and a real, remote, or virtual environment



WHAT CAN HAPTICS BE USED FOR?

- Real – Assistive Interaction
  - Augments human sensing and/or motion capabilities in real physical environments
- Remote – Teleoperation
  - Extends the reach of the human hand to remote, hazardous, unreachable environments

- Virtual – Simulation
  - Enables humans to touch geometric and dynamic computer-based data and models

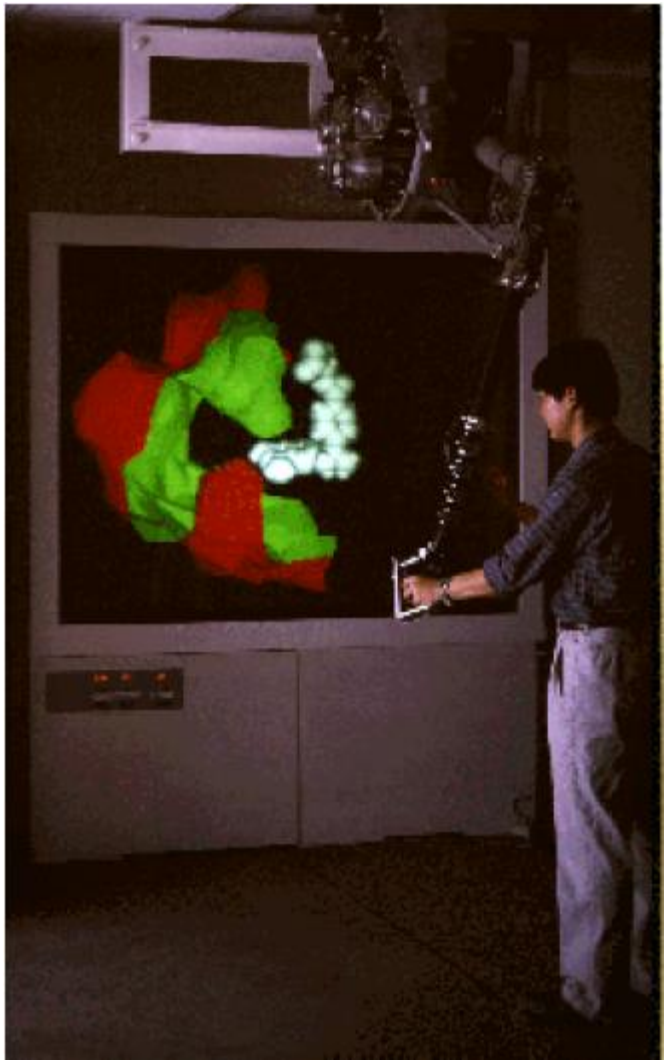
A LITTLE HISTORY

› Ray Goertz, Argonne National Lab, 1940s

https://www.youtube.com/watch?v=7YEMMpngZTE

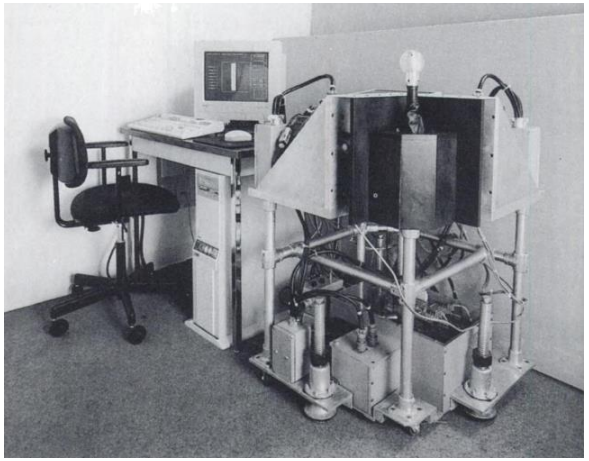
COMPUTER SIMULATION REPLACES THE SLAVE MANIPULATOR

- Fred Brooks, UNC Chapel Hill, 1970s
- Developed to study molecular docking
- User feels interaction force between molecules
- Master was one of Goertz's
- Didn't work very well…

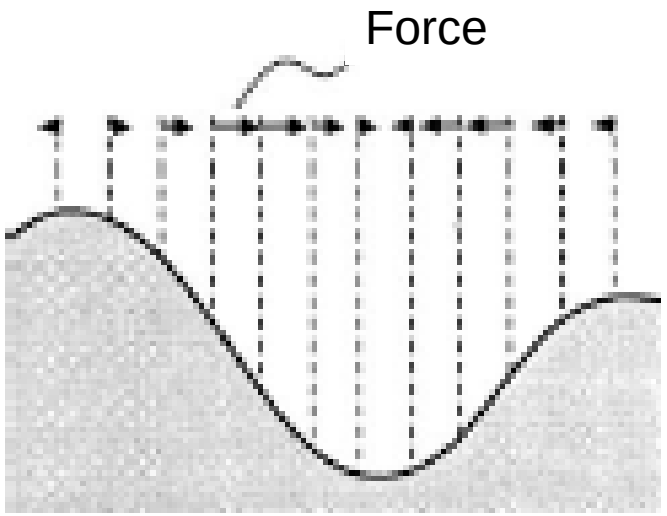


~1990 – HAPTIC INTERFACE EMERGES AS AN ENGINEERING DISCIPLINE

- Margaret Minsky's "virtual sandpaper" system developed at the MIT Media Lab
- Dov Adelstein's force reflecting joystick developed in the MIT Biomechanics Lab



Minsky, 1990



PHANTOM HAPTIC DEVICE

- In 1995, Massie and Salisbury developed the PHANToM (Personal HAptic iNTerface Mechanism) system
- This cable-driven device design became incredibly popular

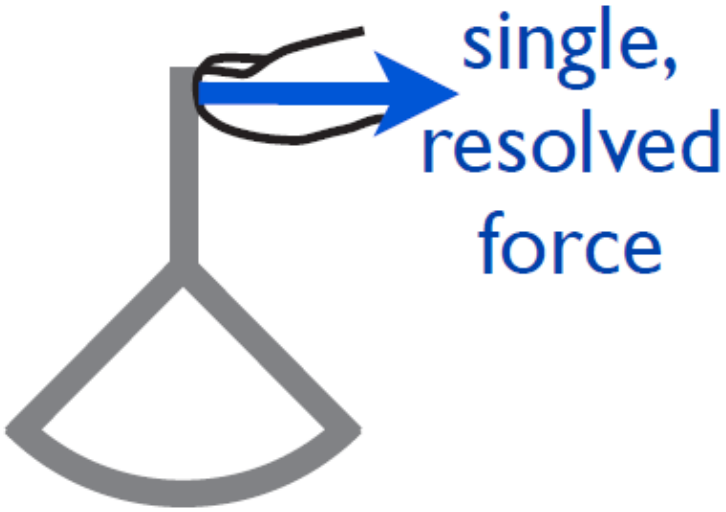

da Vinci S

APPROACHES TO HAPTIC DEVICES

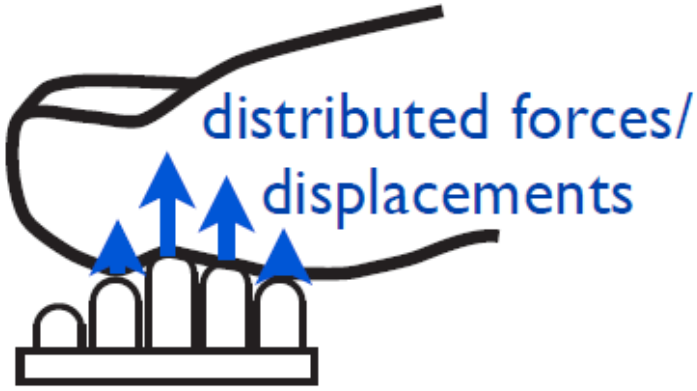
- Grounded force feedback devices
- Body-grounded & wearable devices
- Vibrotactile devices
- Inertial vibrotactile devices
- Pin arrays
- Surface haptic devices
- Mid-air haptics
- …

HAPTIC DEVICES

Kinesthetic haptic devices display forces or motions through a tool.

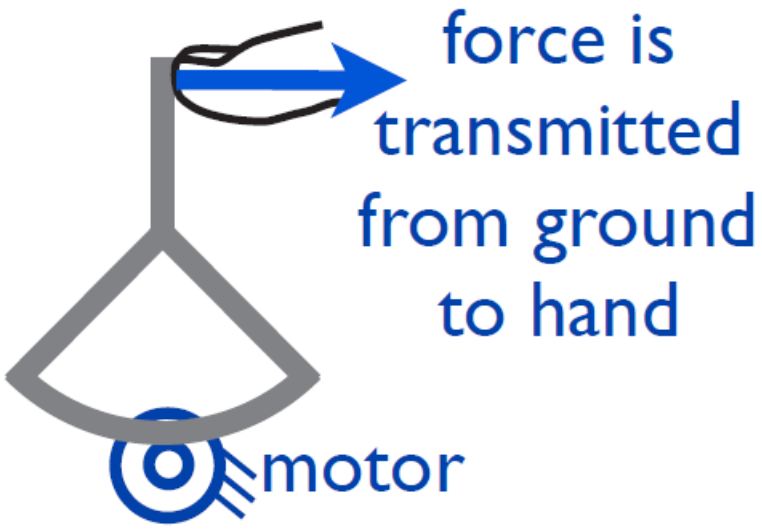


Tactile haptic devices stimulate the skin

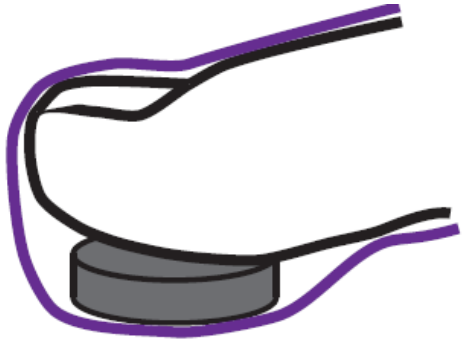


HAPTIC DEVICES

Kinesthetic haptic devices are usually **grounded**



Tactile haptic devices can more easily be **wearable**



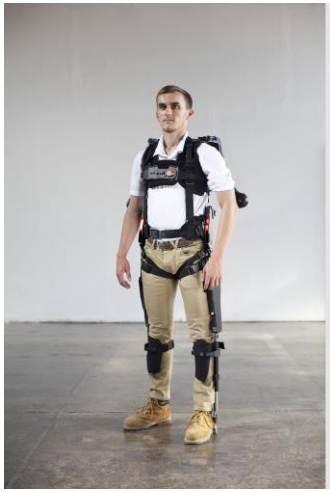
vibration feedback element encased in glove

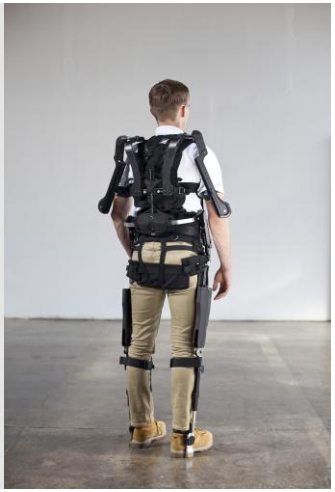
KINESTHETIC DEVICE CONFIGURATIONS

- Manipulandum

- Grasp

- Exoskeleton

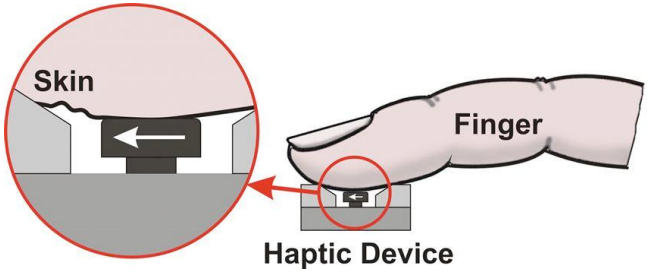




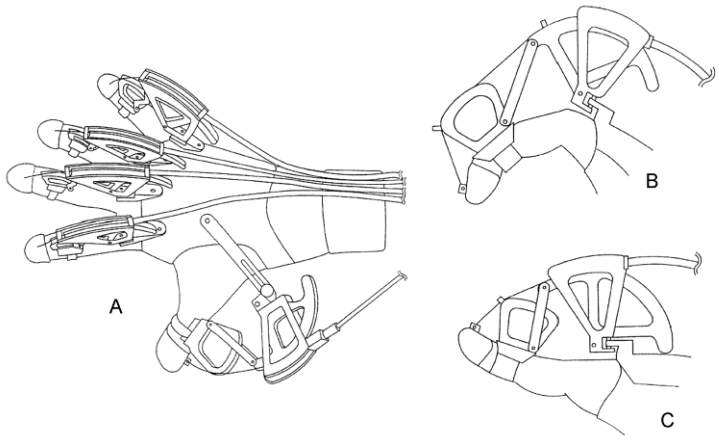
GROUNDED DEVICES

- Phantom and Novint Falcon (impedance style)
- Haptic Master (admittance style)
- List goes on…

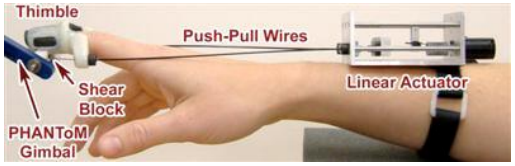
BODY-GROUNDED DEVICES



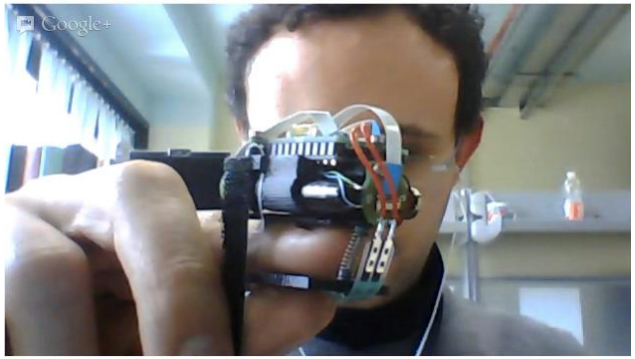
Skin stretch devices (W. Provancher)



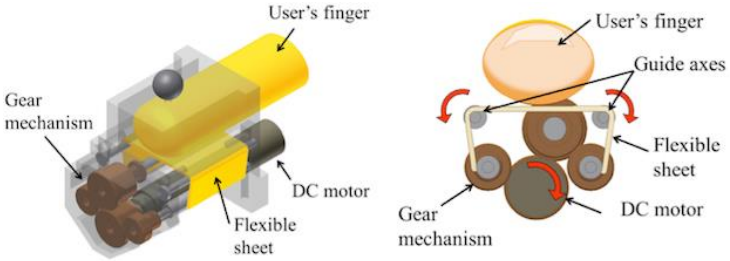
Cybergrasp



Contact Location (Provancher & Tan)

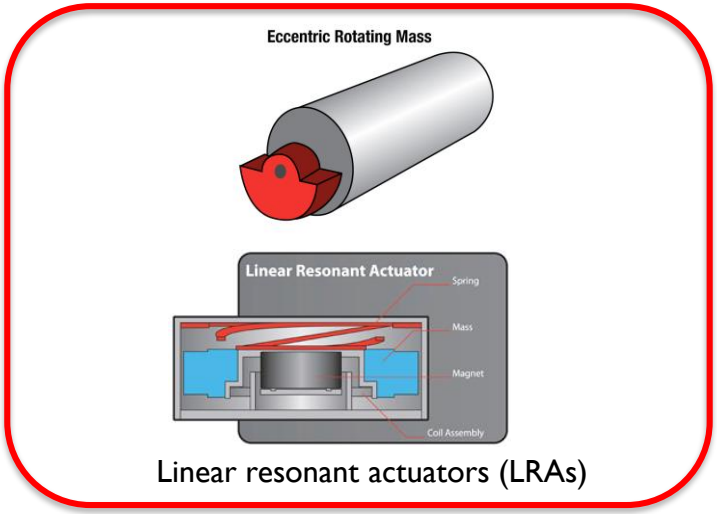


Contact Orientation (D. Prattichizzo)

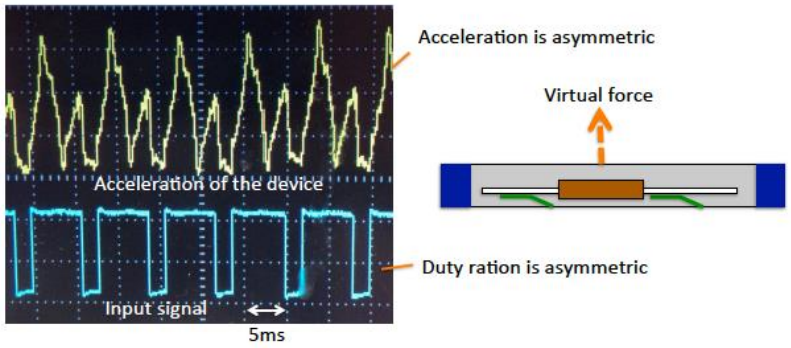


Softness Display (Kawasaki)

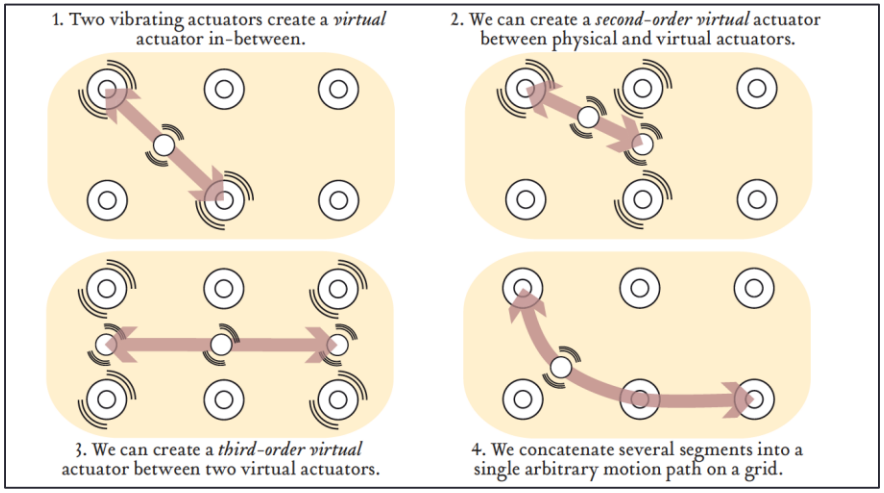
VIBROTACTILE DEVICES



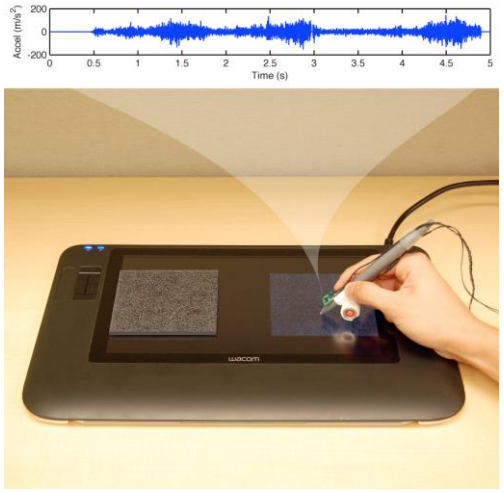
Linear resonant actuators (LRAs)



Asymmetric acceleration produces virtual force (Rekimoto)



Array of tactors coupled with tactile illusions (Israr)

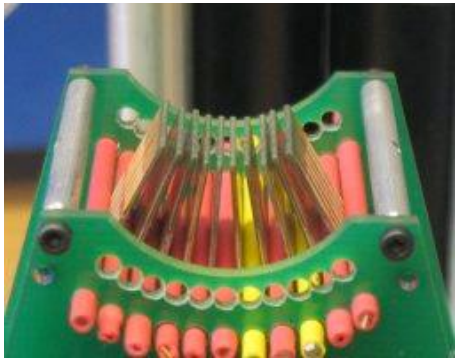


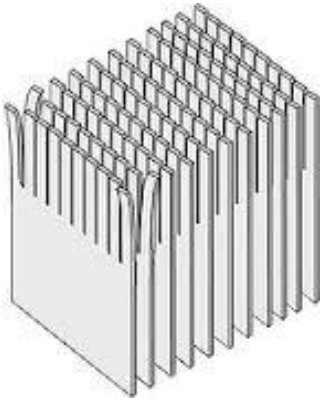
Voice Coil for "Haptography" (Culbertson)

Using "Haptuator" from Tactile Labs

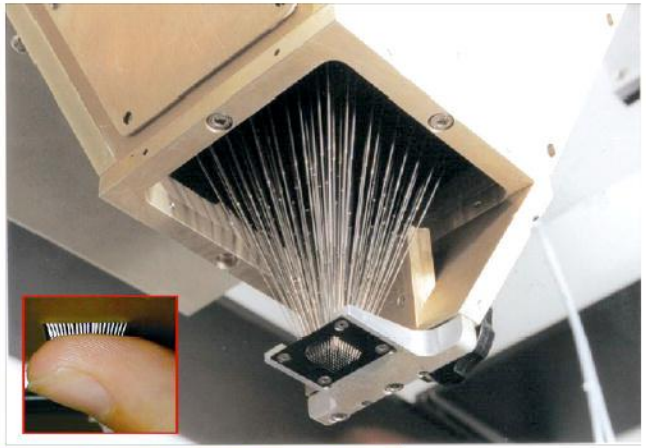
PIN ARRAYS

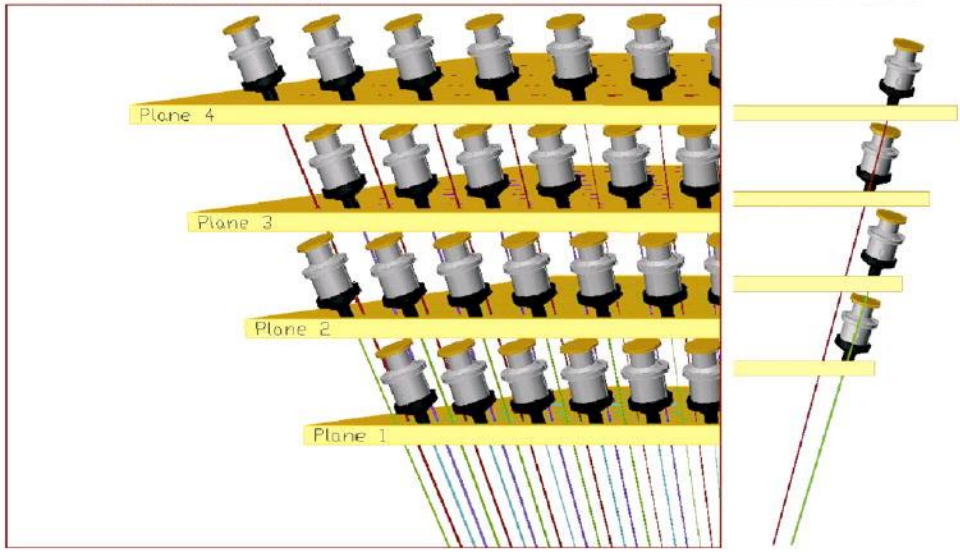
Typical pin array (source unknown)





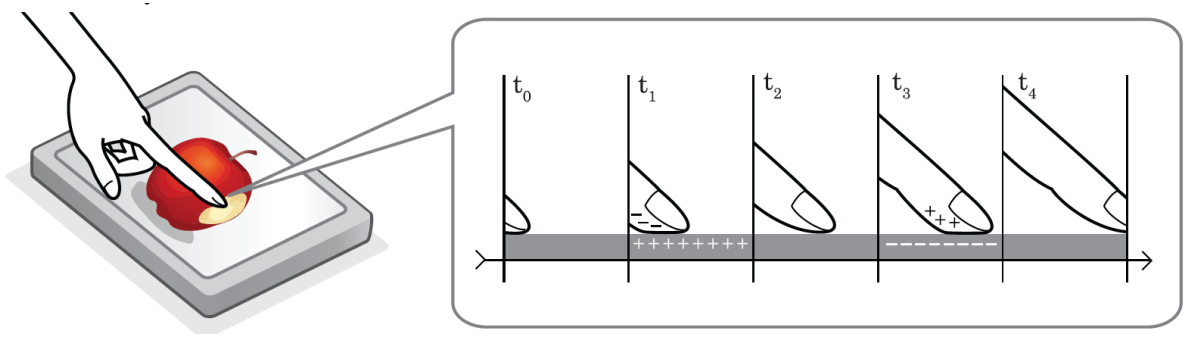
STReSS Lateral Skin Stretch (Hayward)





400 probe stimulator from Johnson lab at JHU

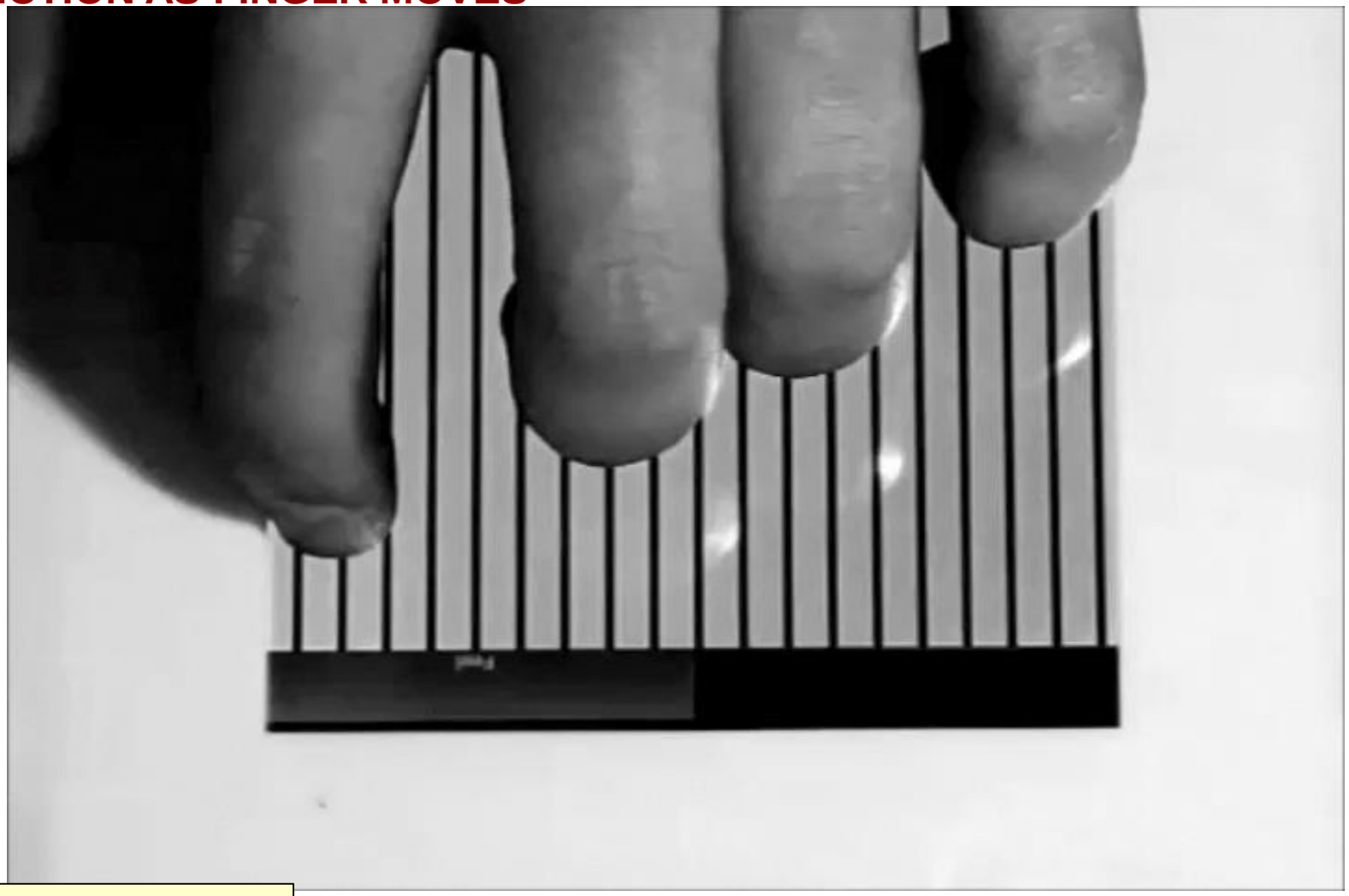
SURFACE HAPTICS



Electrostatic attraction increases friction (Poupyrev, Disney Research)

TPad – ultrasonic vibrations reduce friction (Colgate, Northwestern)

HAPTIC EFFECTS SUCH AS TEXTURE ARE CREATED BY MODULATING FRICTION AS FINGER MOVES



Video courtesy of J. Mullenbach

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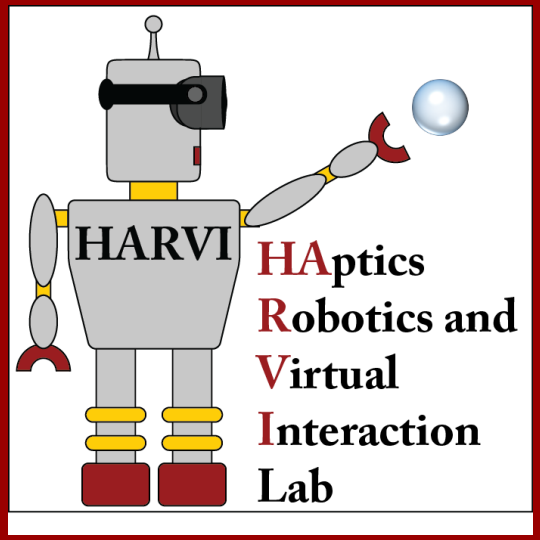
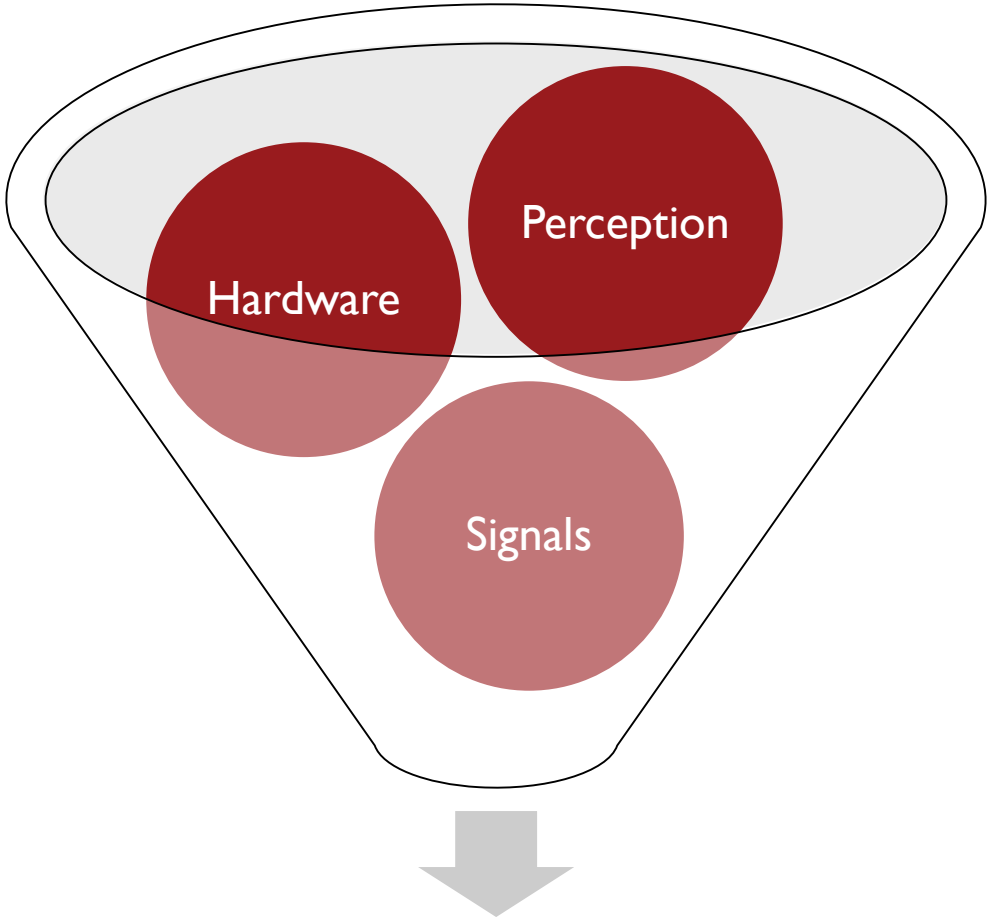
HARVI LAB



OUR APPROACH



Realism and Immersiveness

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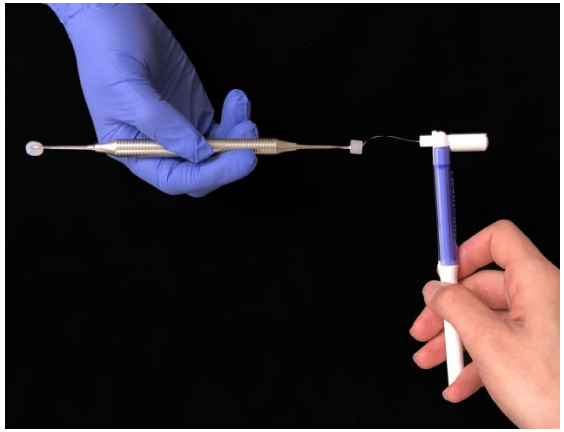
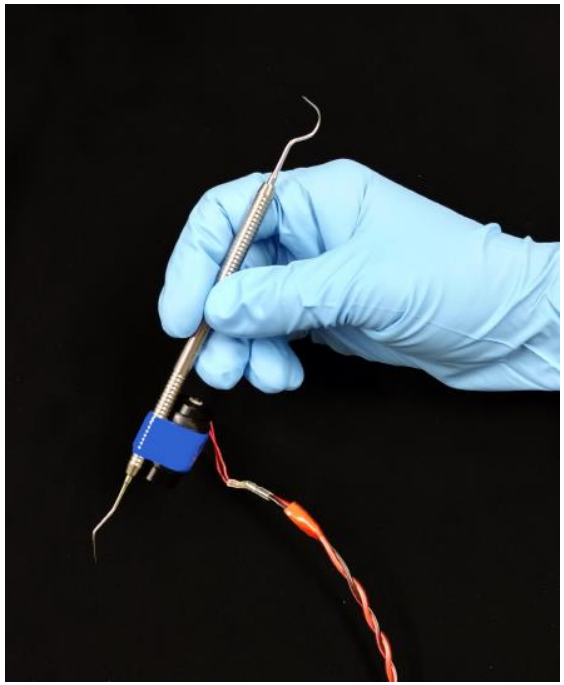
EFFECTS OF DENTAL GLOVES ON PERCEPTION

TOOL VS. FINGER CONTACT

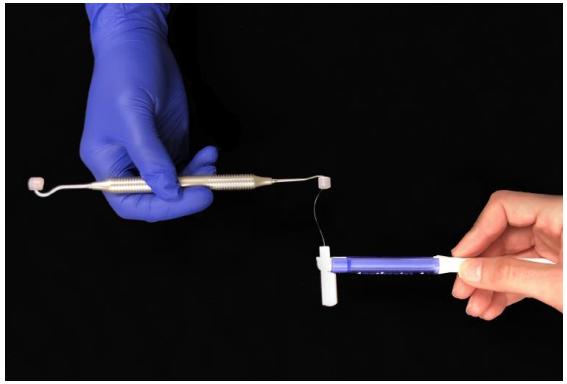
KEY TOUCH SENSATIONS



Force

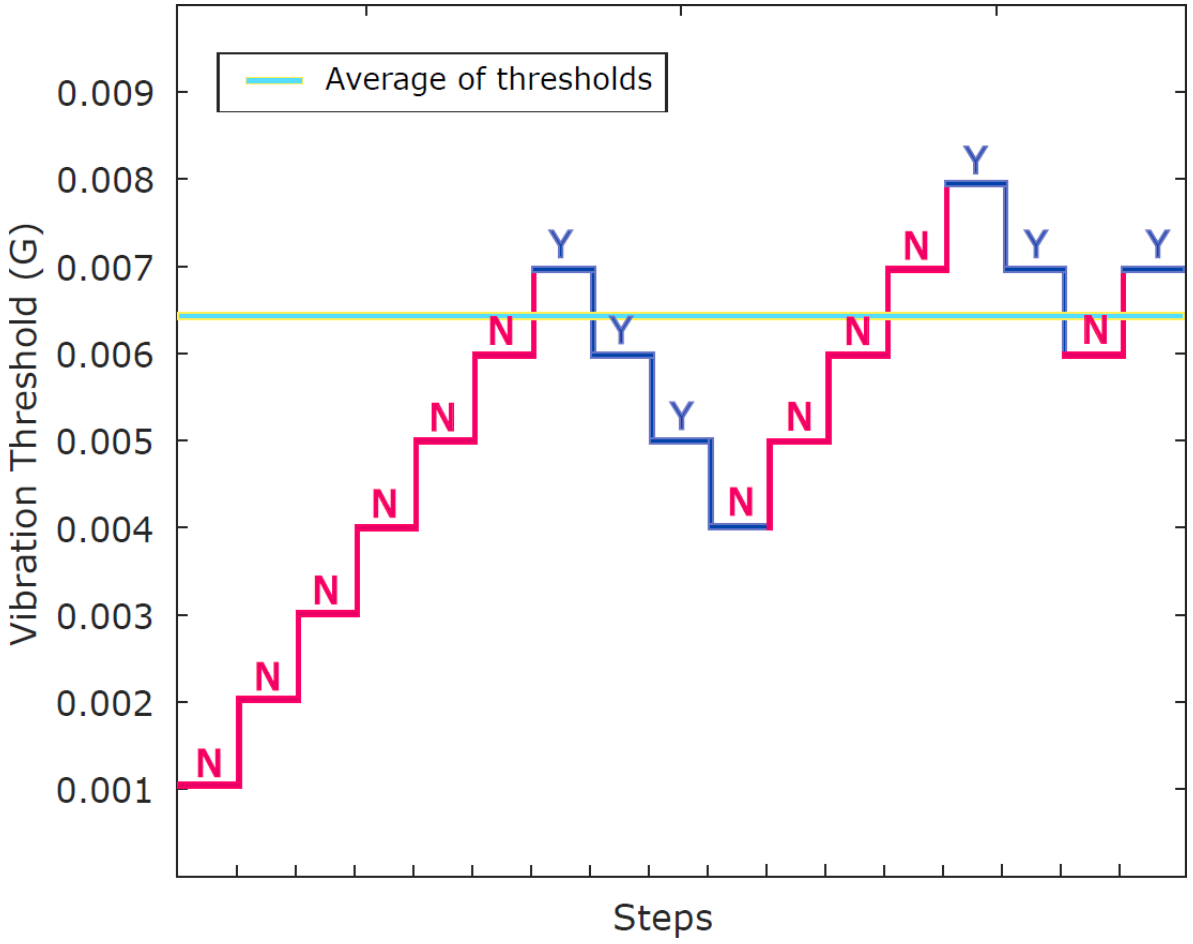


Vibration

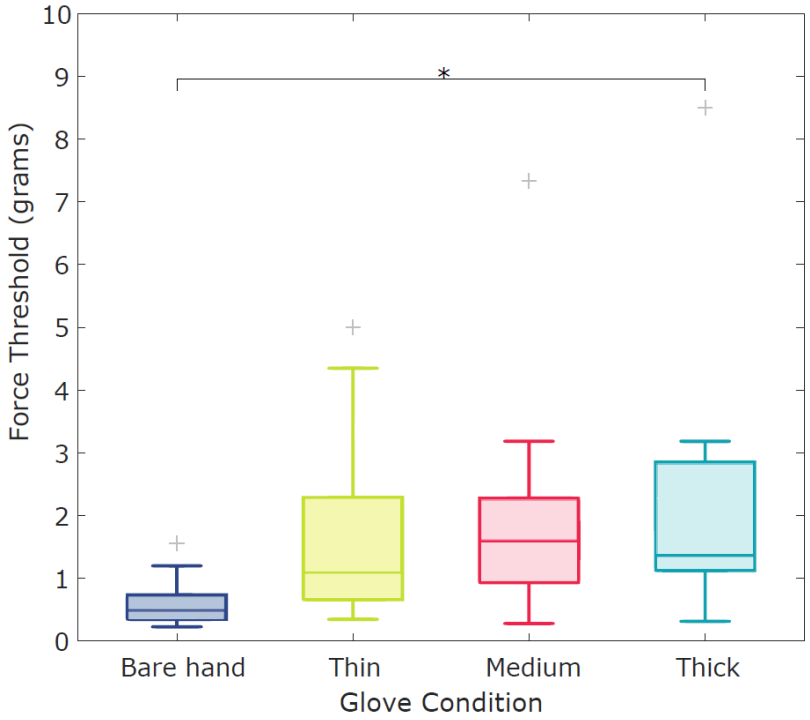


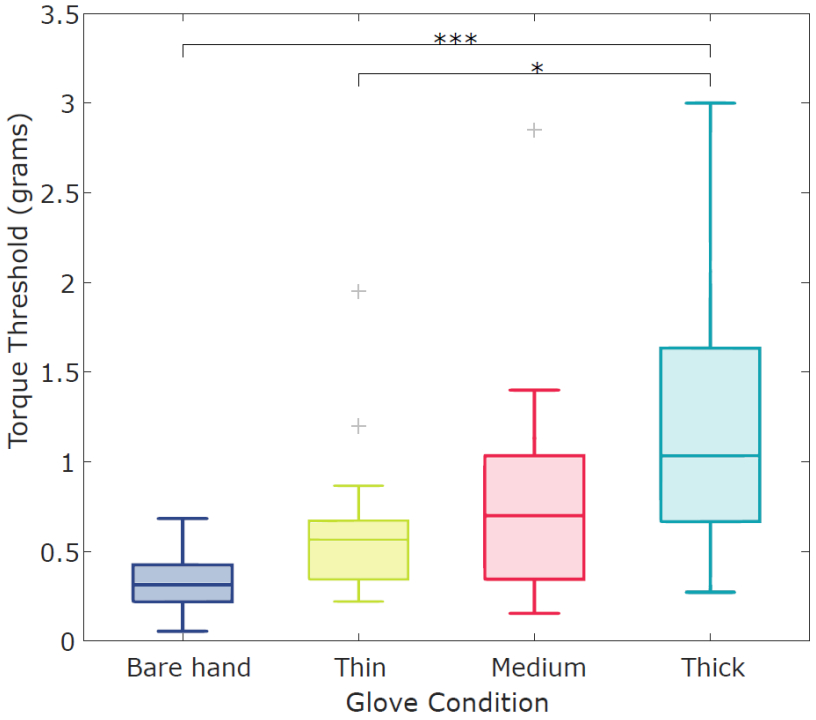
Torque

PERCEPTUAL THRESHOLD



FORCE/TORQUE THRESHOLDS





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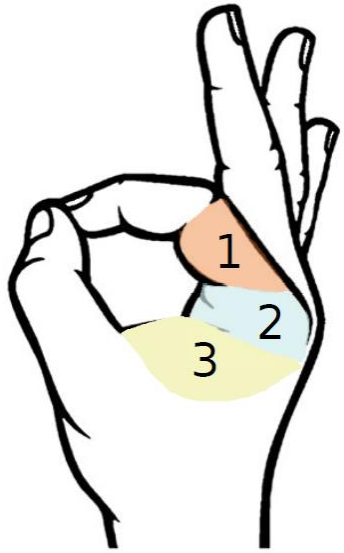
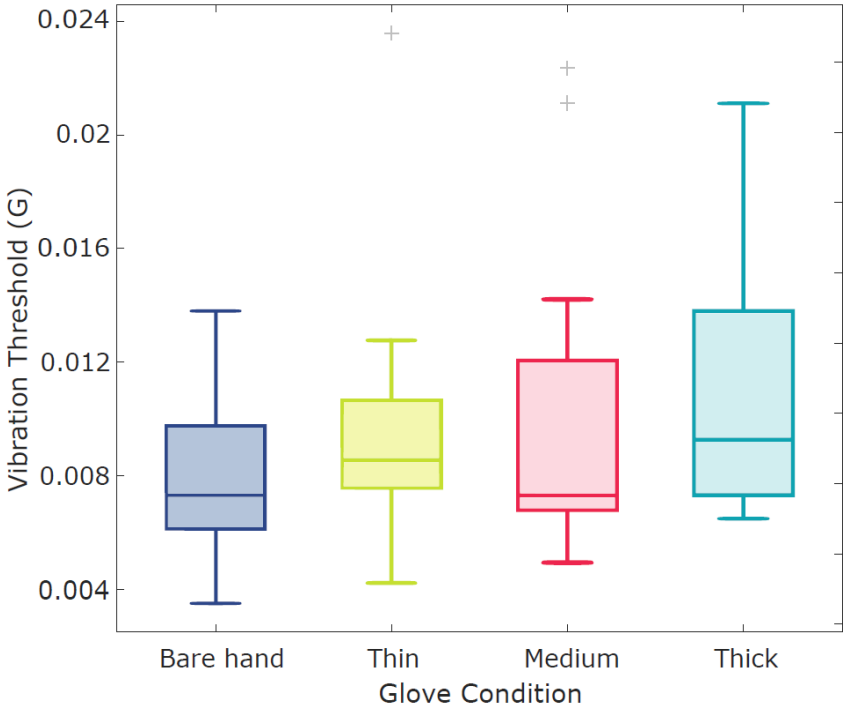
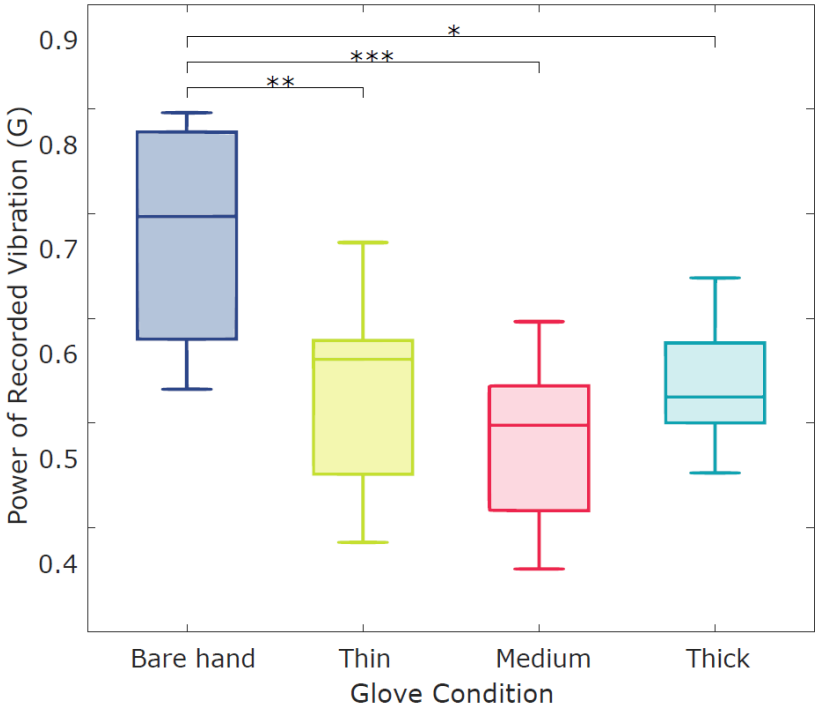
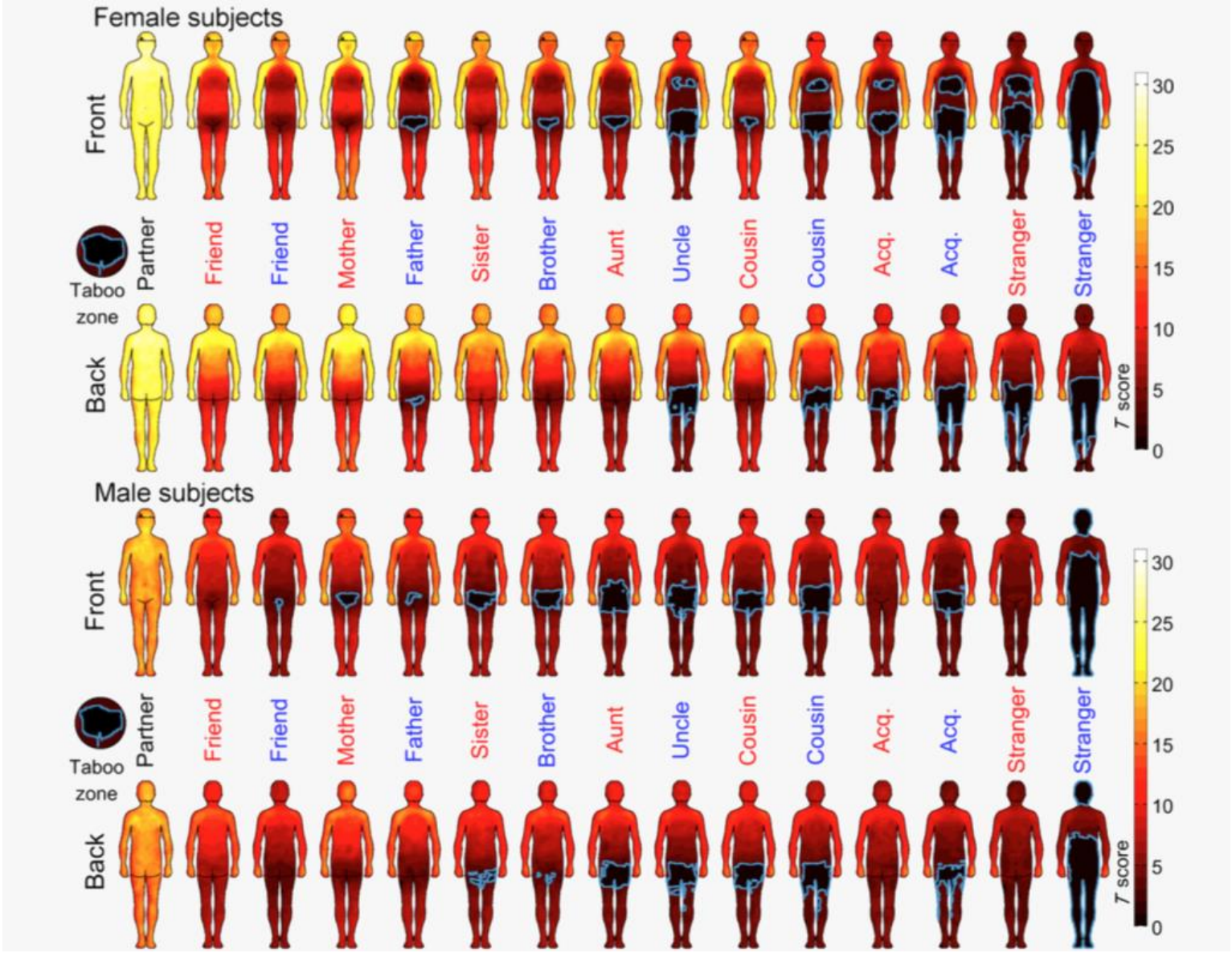
VIBRATION THRESHOLD





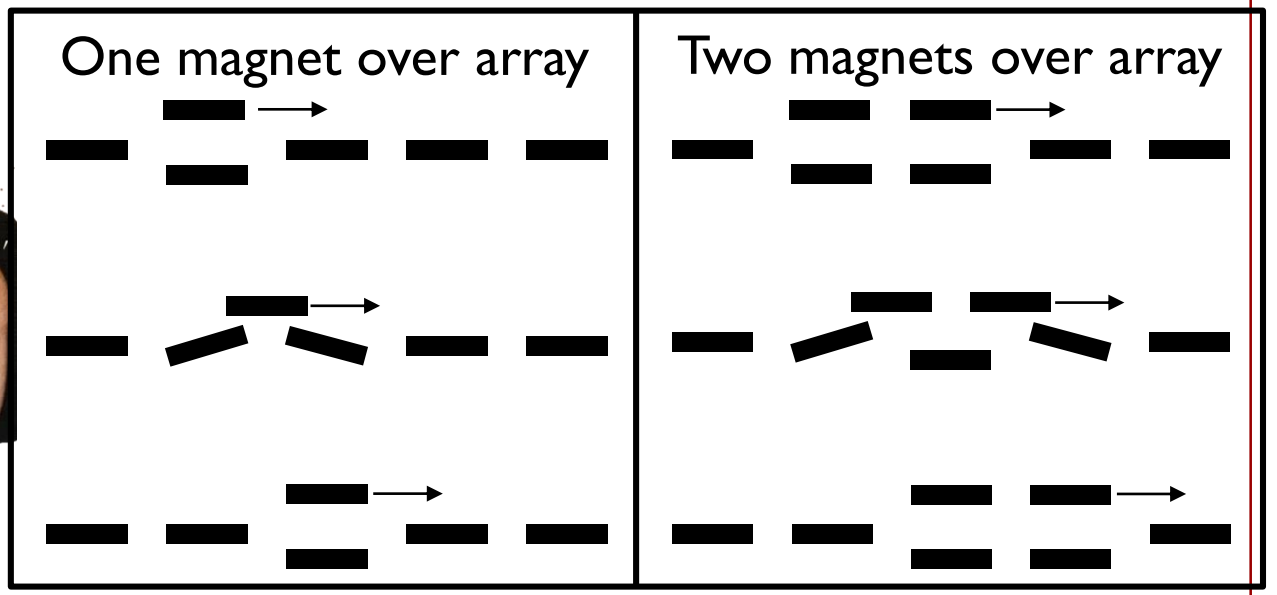


SOCIAL TOUCH



Suvilehto et al., "Topography of social touching depends on emotional bonds between humans", 2015.

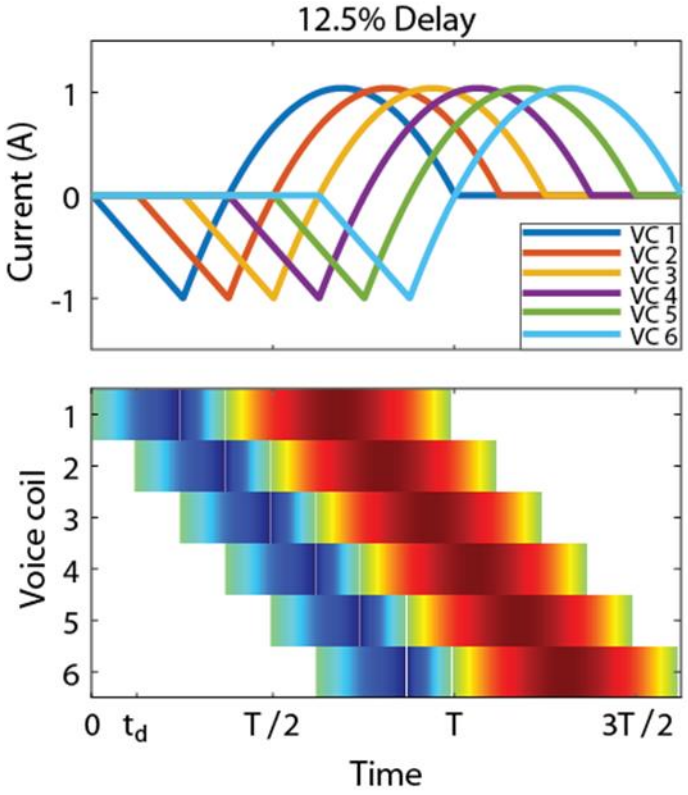
HAPTIC SKETCHING



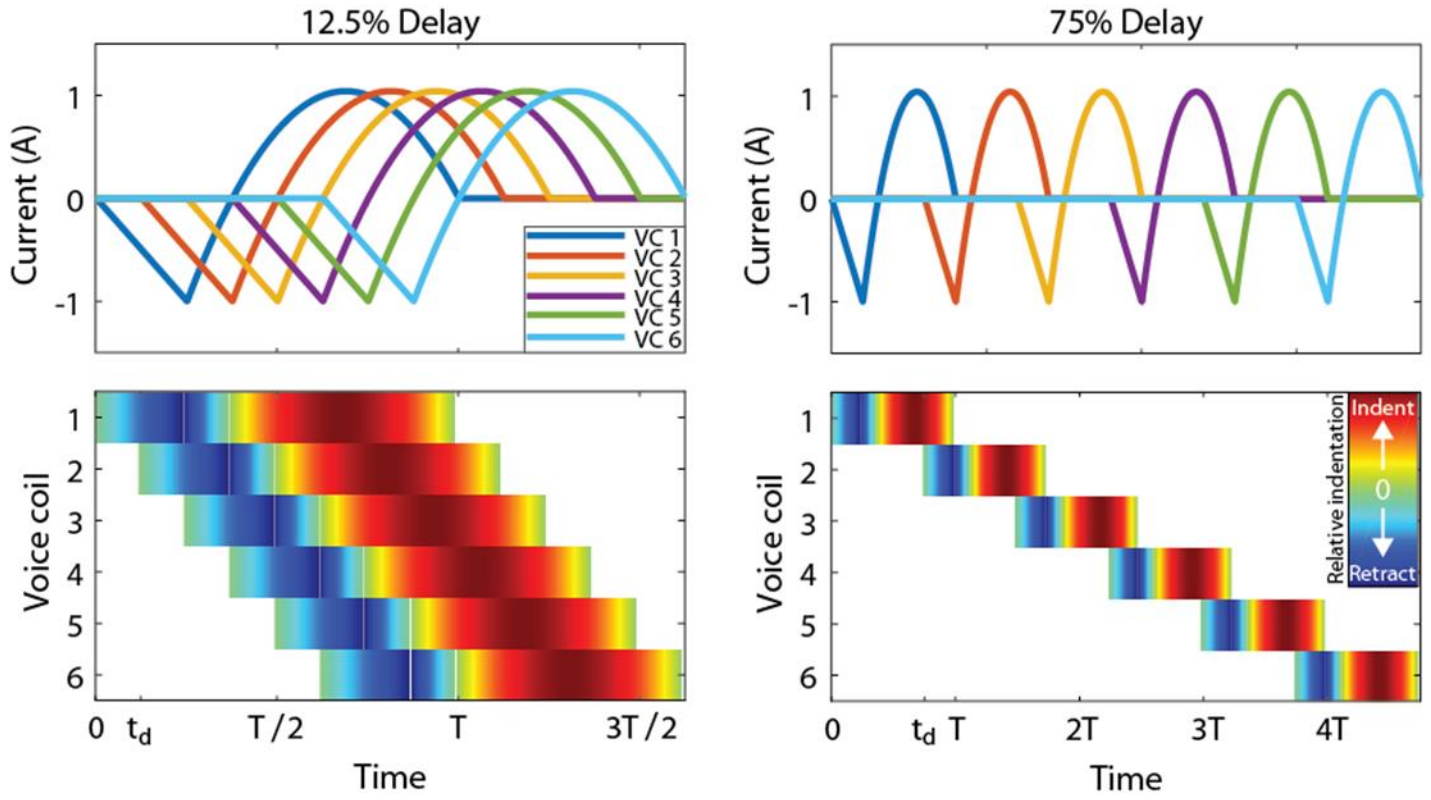
VOICE COIL ARRAY

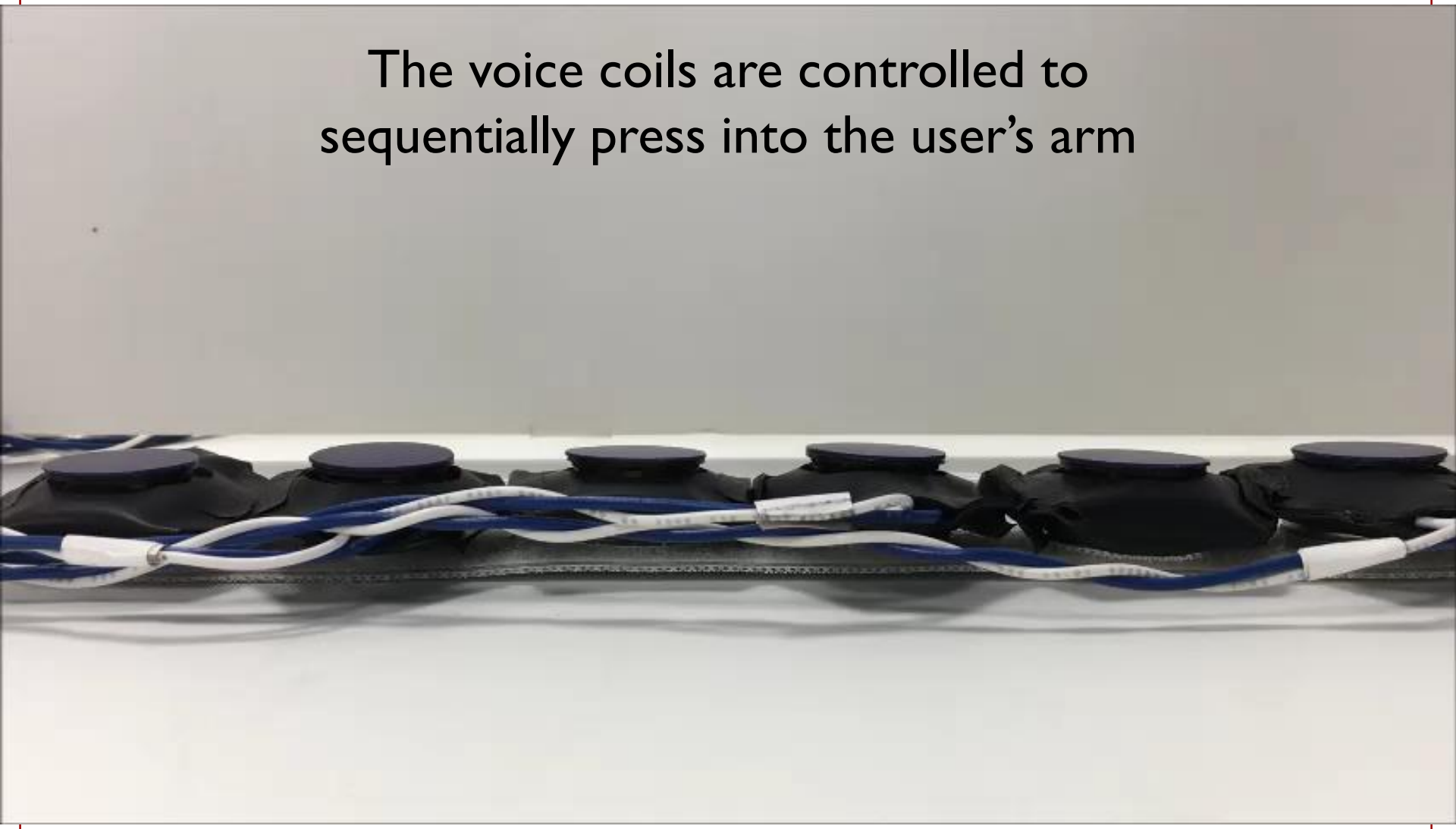
- Hardware Requirements:
  - Apply 1 N force
  - Actuate at low frequencies (1-5 Hz)
  - At least 3 mm of motion

SEQUENTIAL ACTIVATION



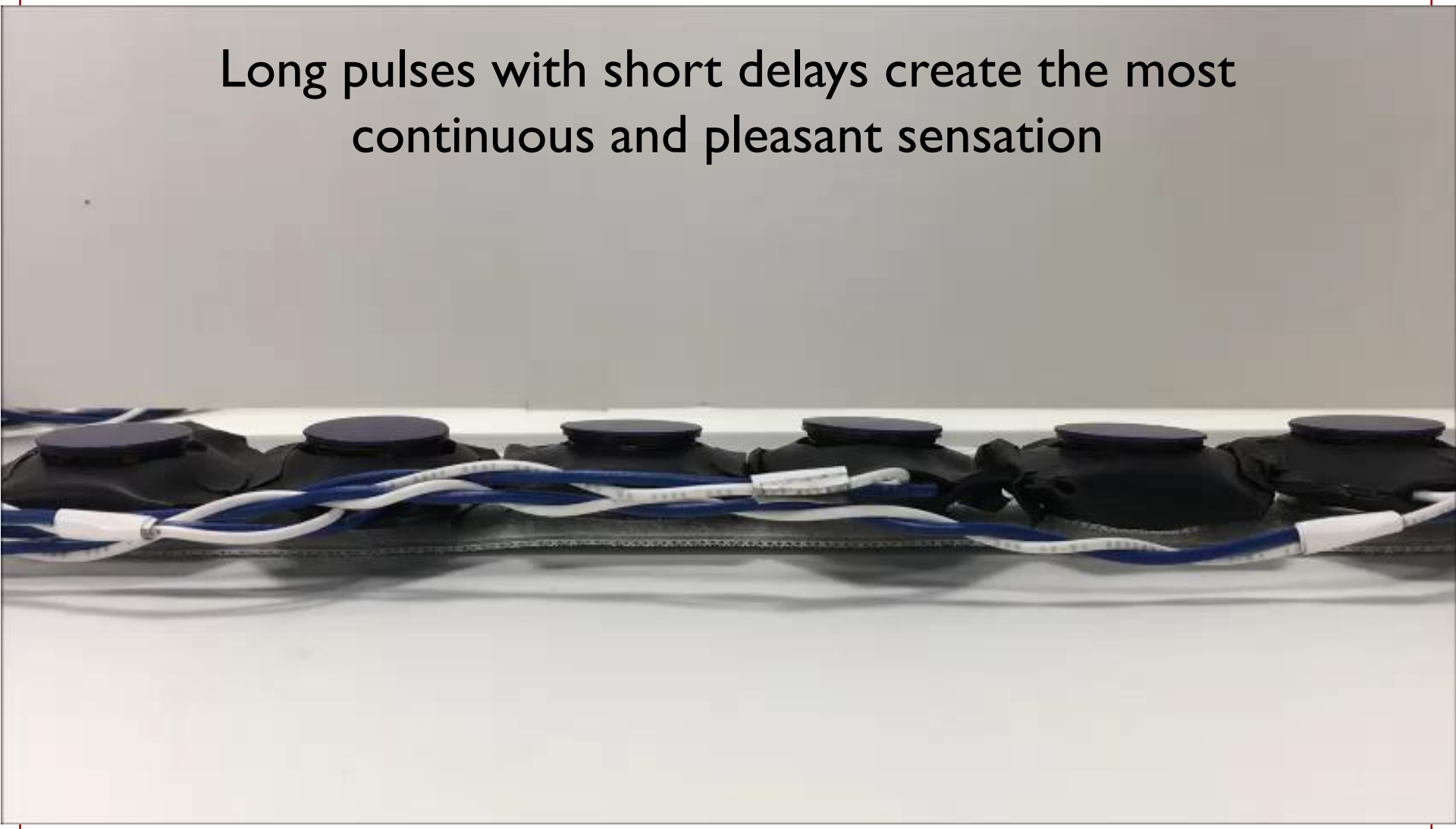
SEQUENTIAL ACTIVATION



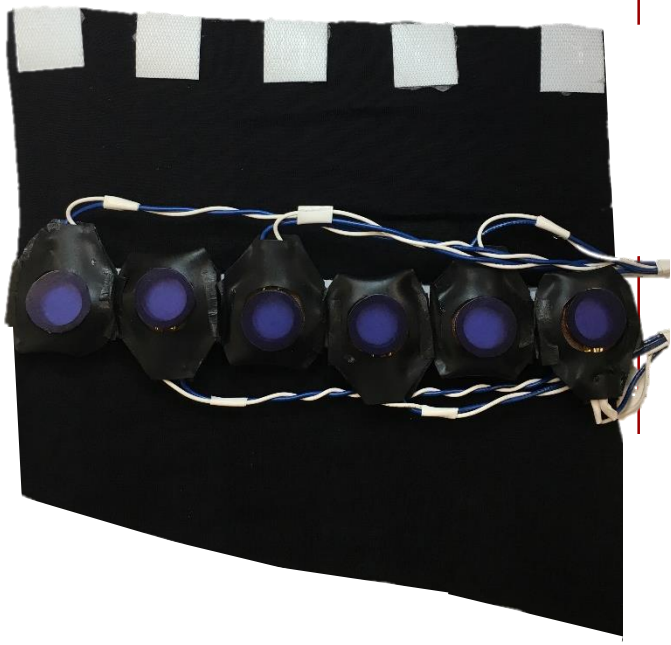

The voice coils are controlled to
sequentially press into the user's arm

Fast pulses with short delays feel unpleasant

Long pulses with short delays create the most continuous and pleasant sensation



WEARABLE SYSTEM



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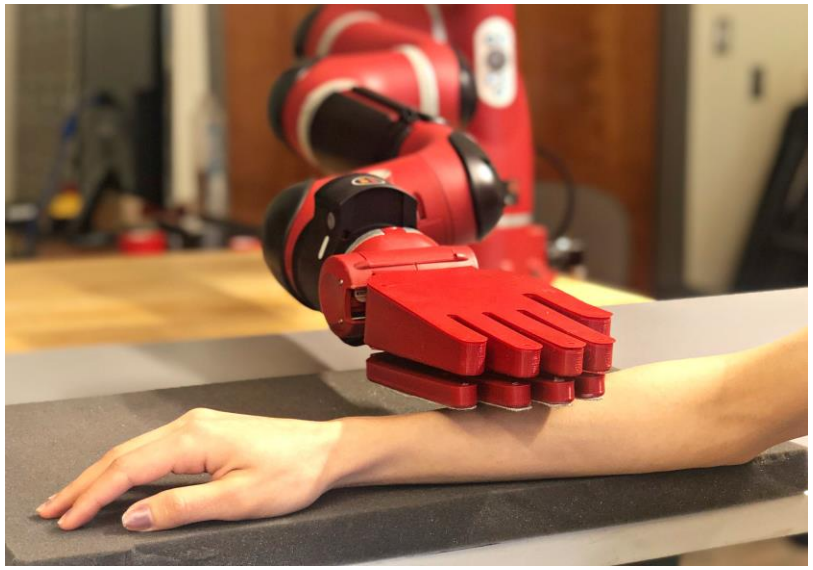
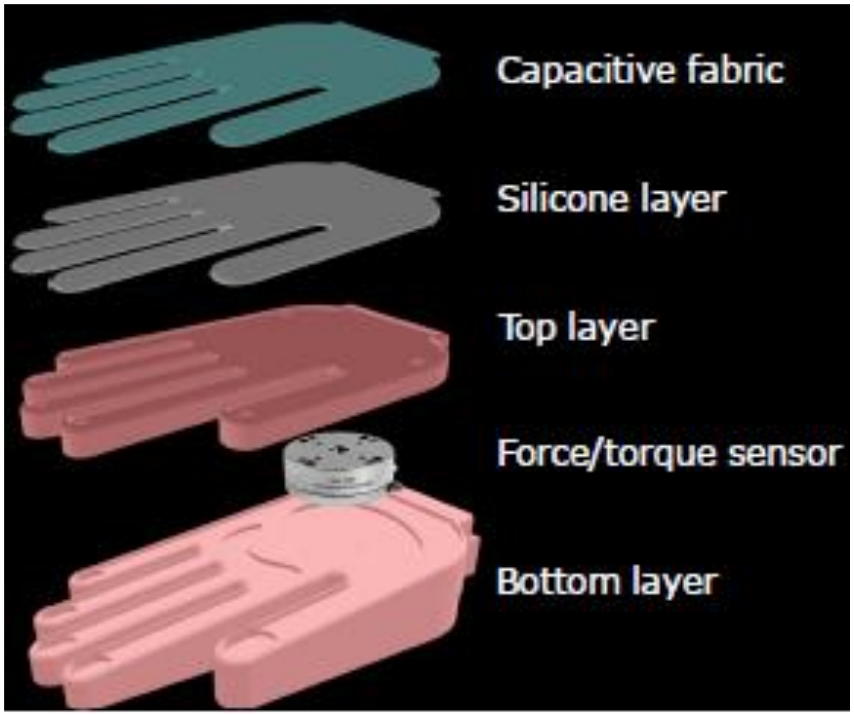
ROBOT SOCIAL TOUCH

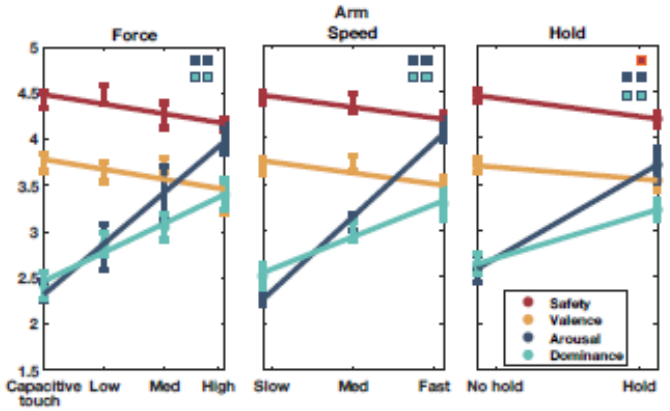
ROBOT PATTING



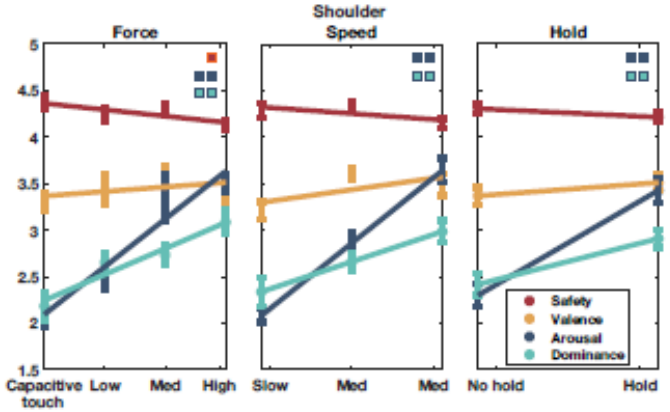
SENSING


Capacitive fabric
Silicone layer
Top layer
Force/torque sensor
Bottom layer

RESULTS



(a)



(b)

TABLE 1
Mean and standard deviation of post survey ratings

Questions	Mean	Std
I could corporate with the robot	3.7	0.8
I like the presence of the robot	3.5	1.3
I could do activities with this robot	3.5	1.4
I felt threatened by the robot	1.2	0.4
I consider the robot to be a social agent	3.1	1.6
I feel comfortable while interacting with the robot	3.7	1.4
I trust the robot	3.5	3

*5=strongly agree, 1=strongly disagree

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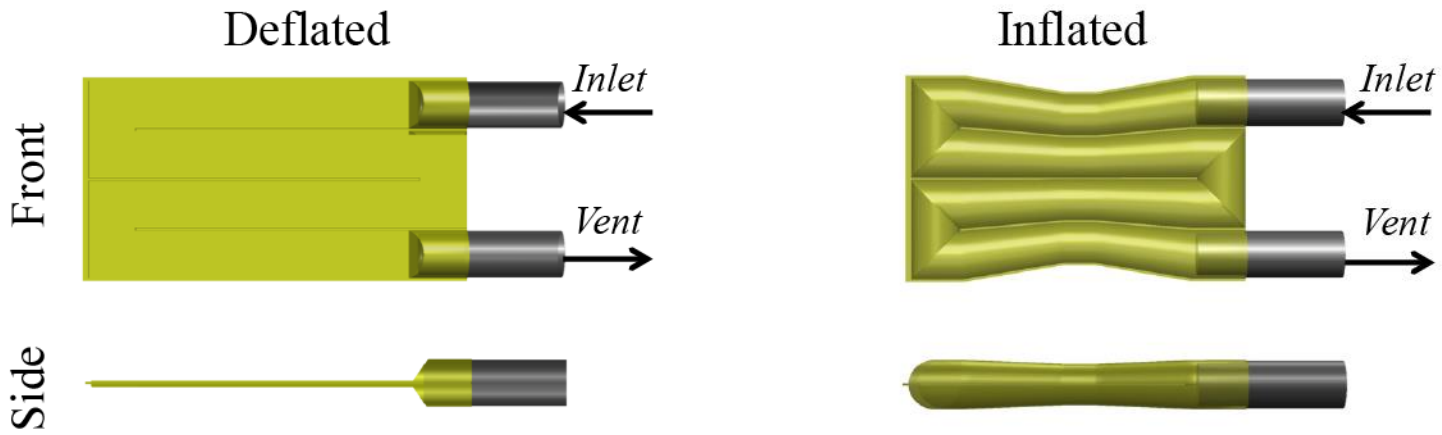
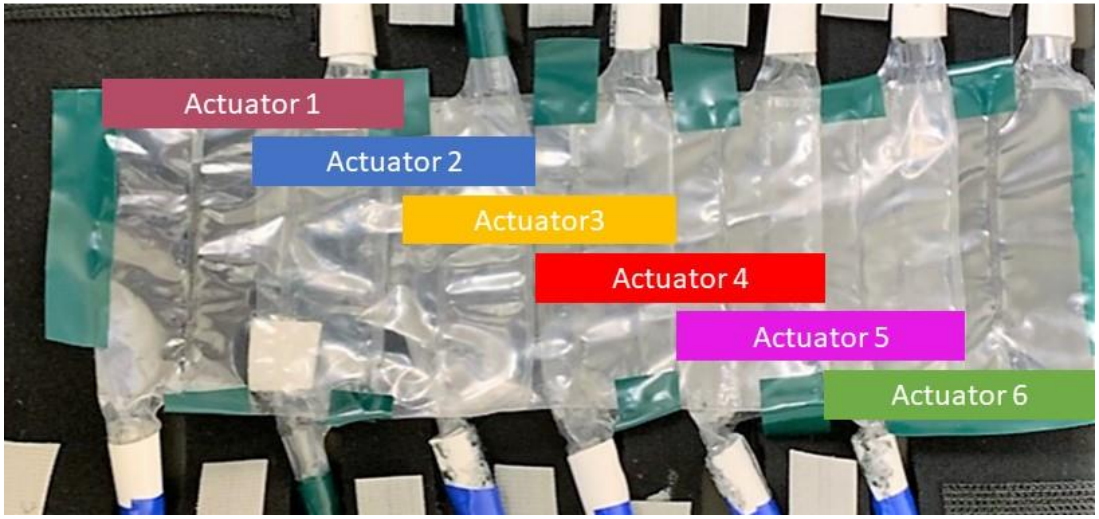
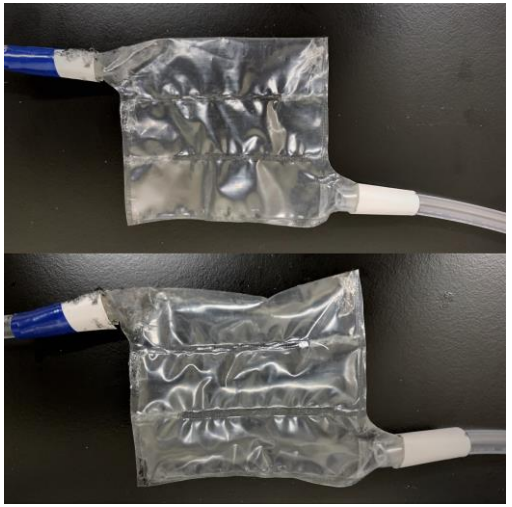
LIGHTWEIGHT WEARABLE HAPTICS

THERMOPLASTIC PNEUMATIC ACTUATORS

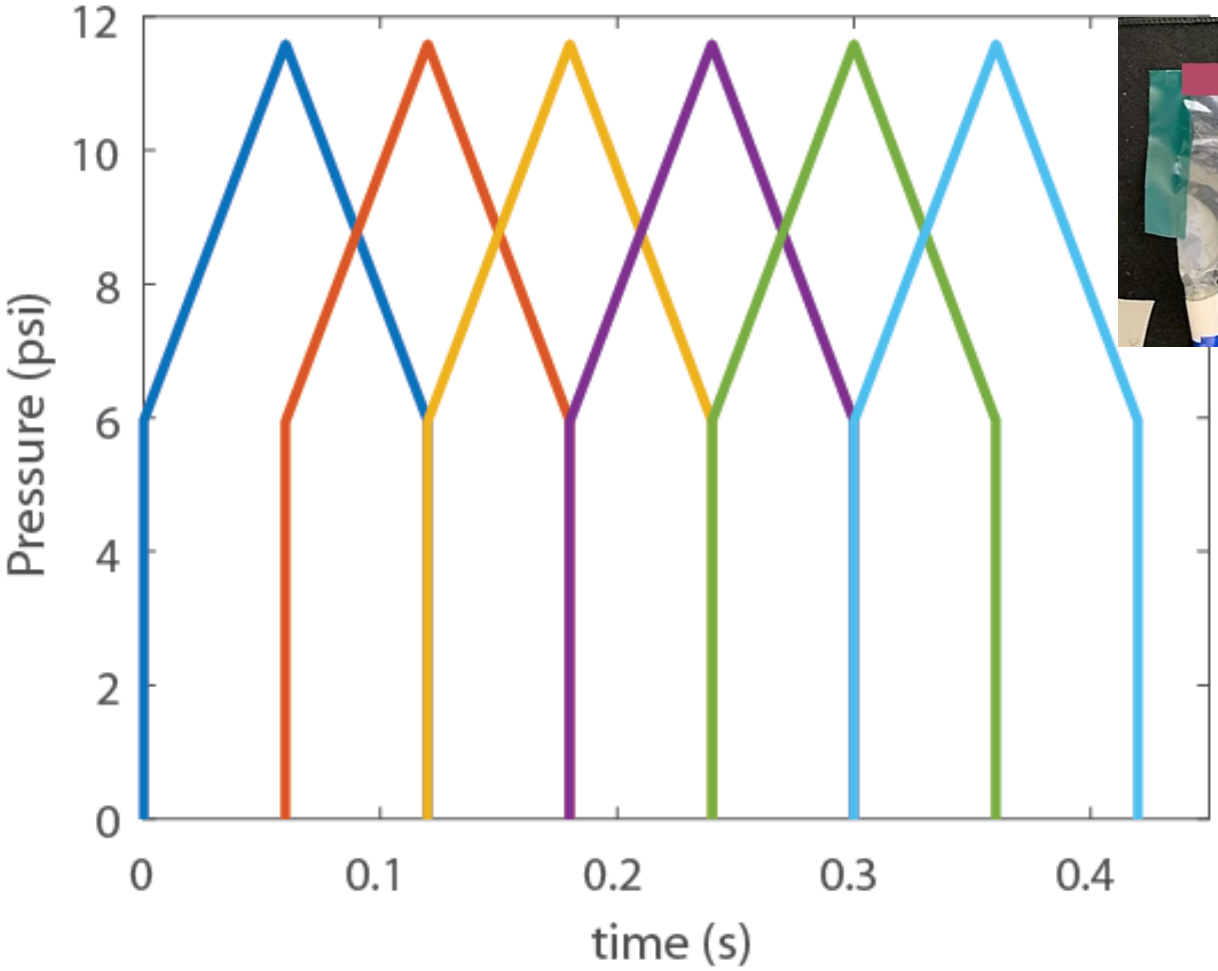


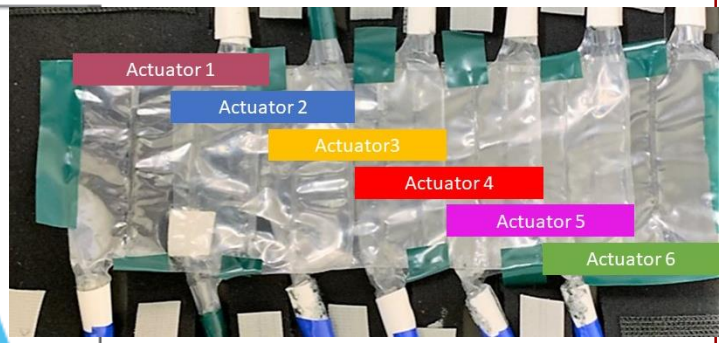
ARRAY OF PNEUMATIC ACTUATORS



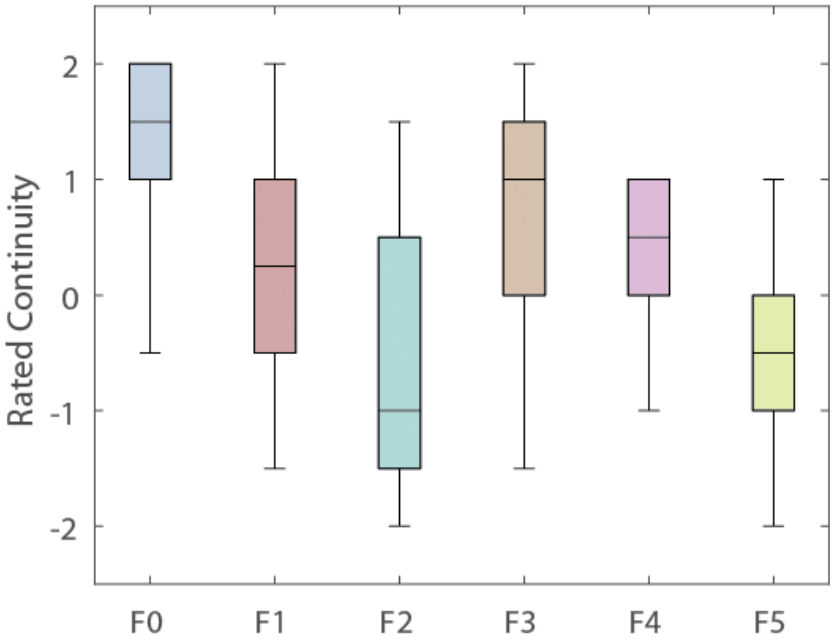


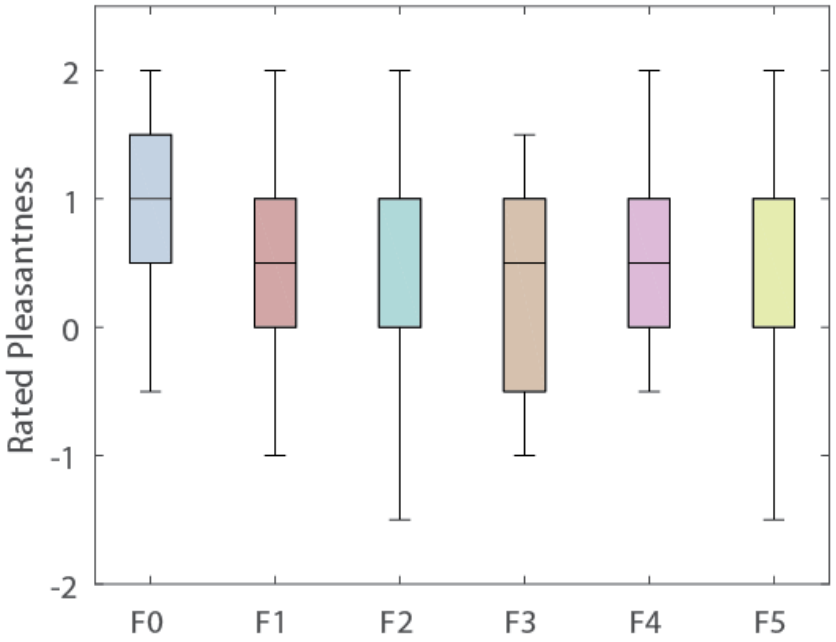
ARRAY CONTROL SIGNALS





TUNING ARRAY CONTROL SIGNALS





	t_l	A_{min}	A_{max}
Function0	120 ms	5.95 psi	11.59 psi
Function1	240 ms	5.95 psi	11.59 psi
Function2	480 ms	5.95 psi	11.59 psi
Function3	120 ms	5.02 psi	6.65 psi
Function4	240 ms	5.02 psi	6.65 psi
Function5	480 ms	5.02 psi	6.65 psi

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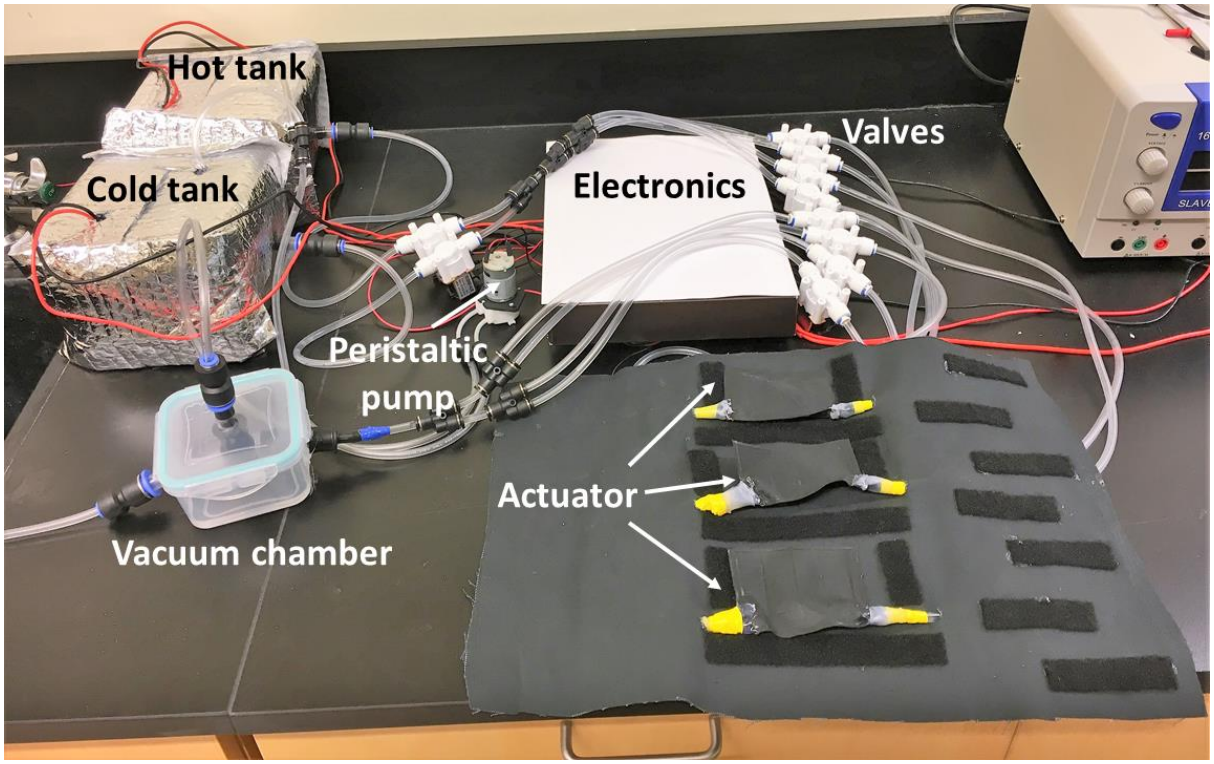
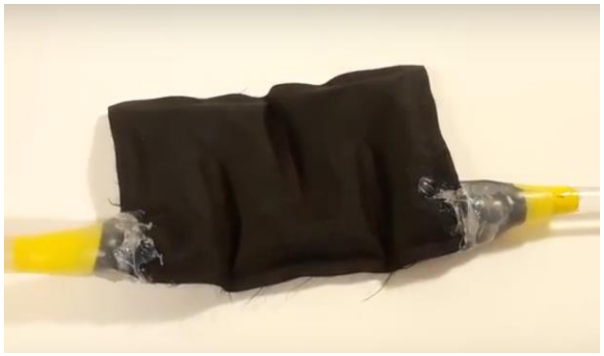
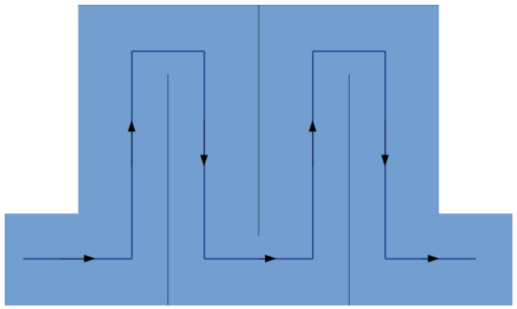
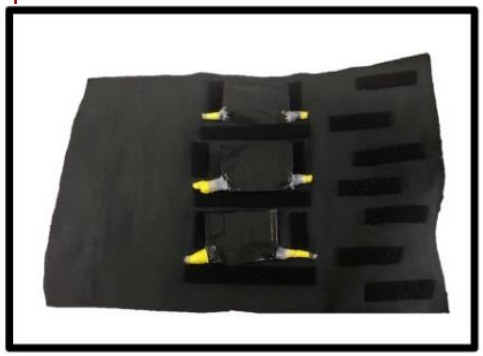
PATCH: PUMP-ACTUATED THERMAL COMPRESSION HAPTICS



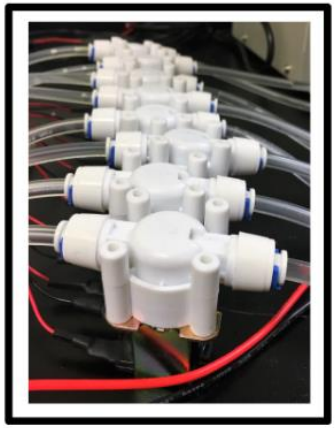




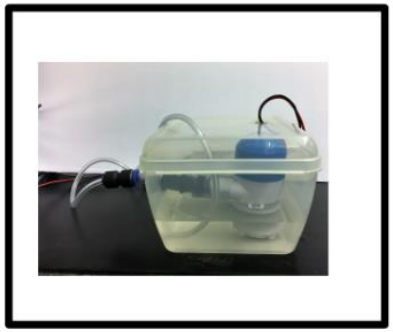
SYSTEM DESIGN



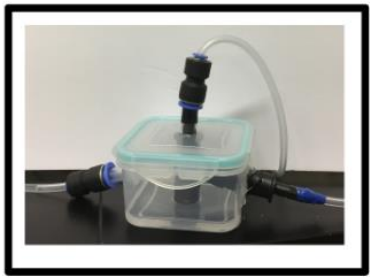
(a)



(c)



(b)



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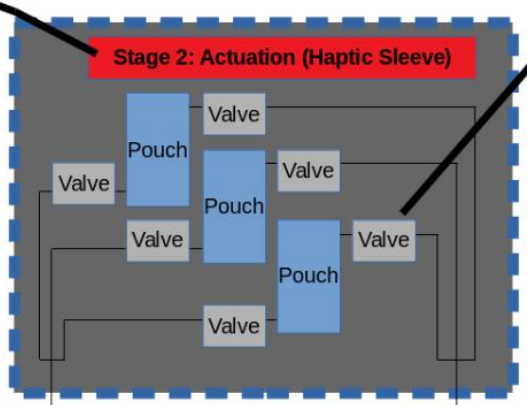

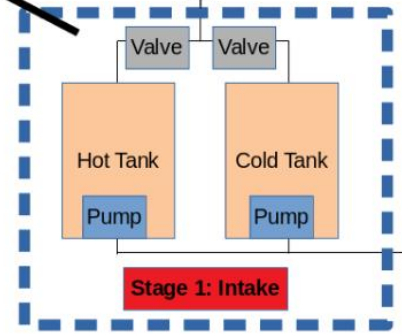

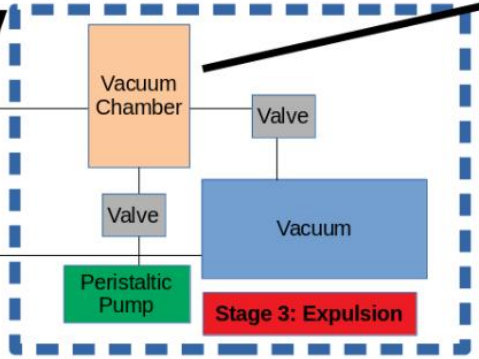

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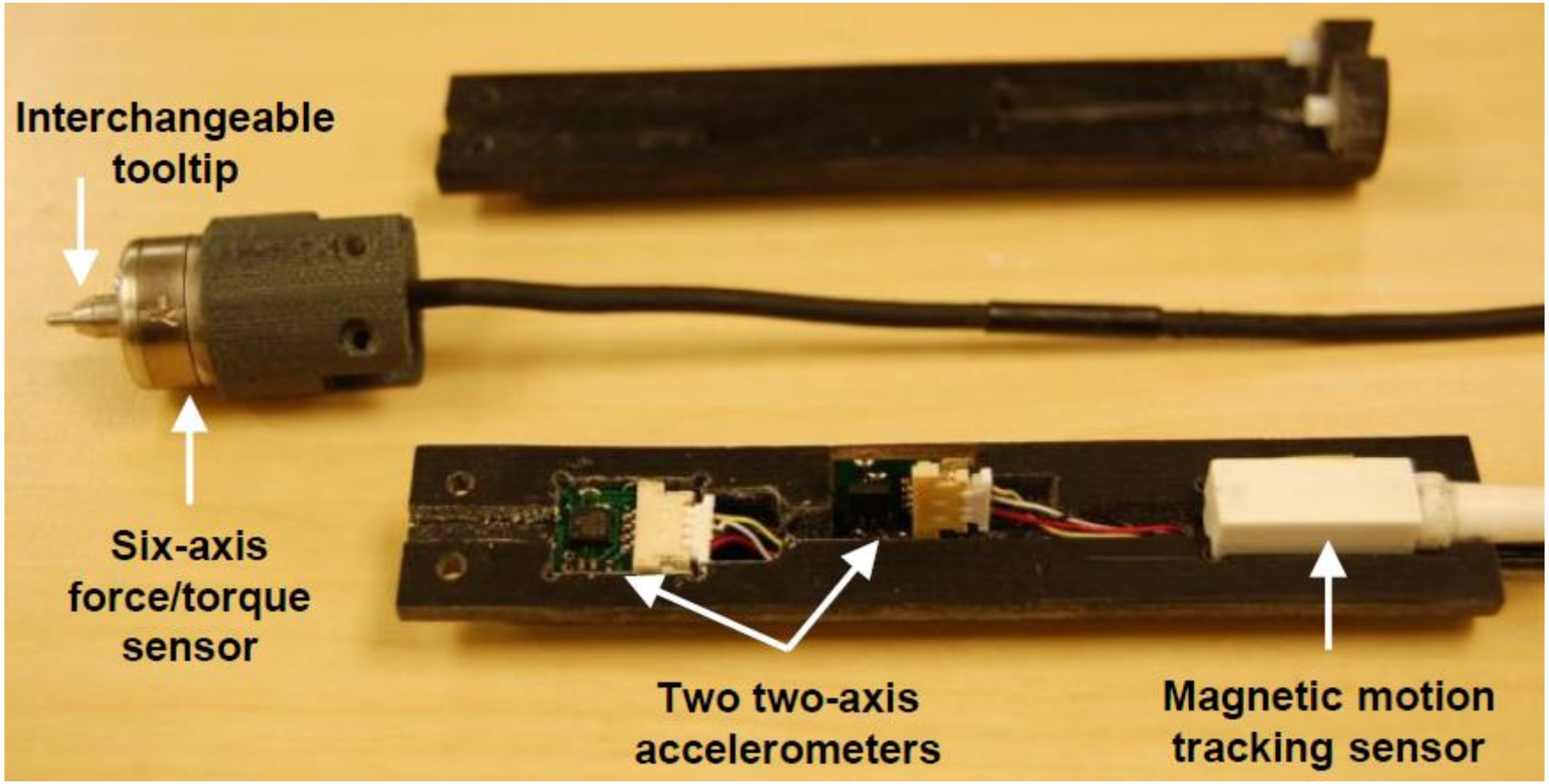
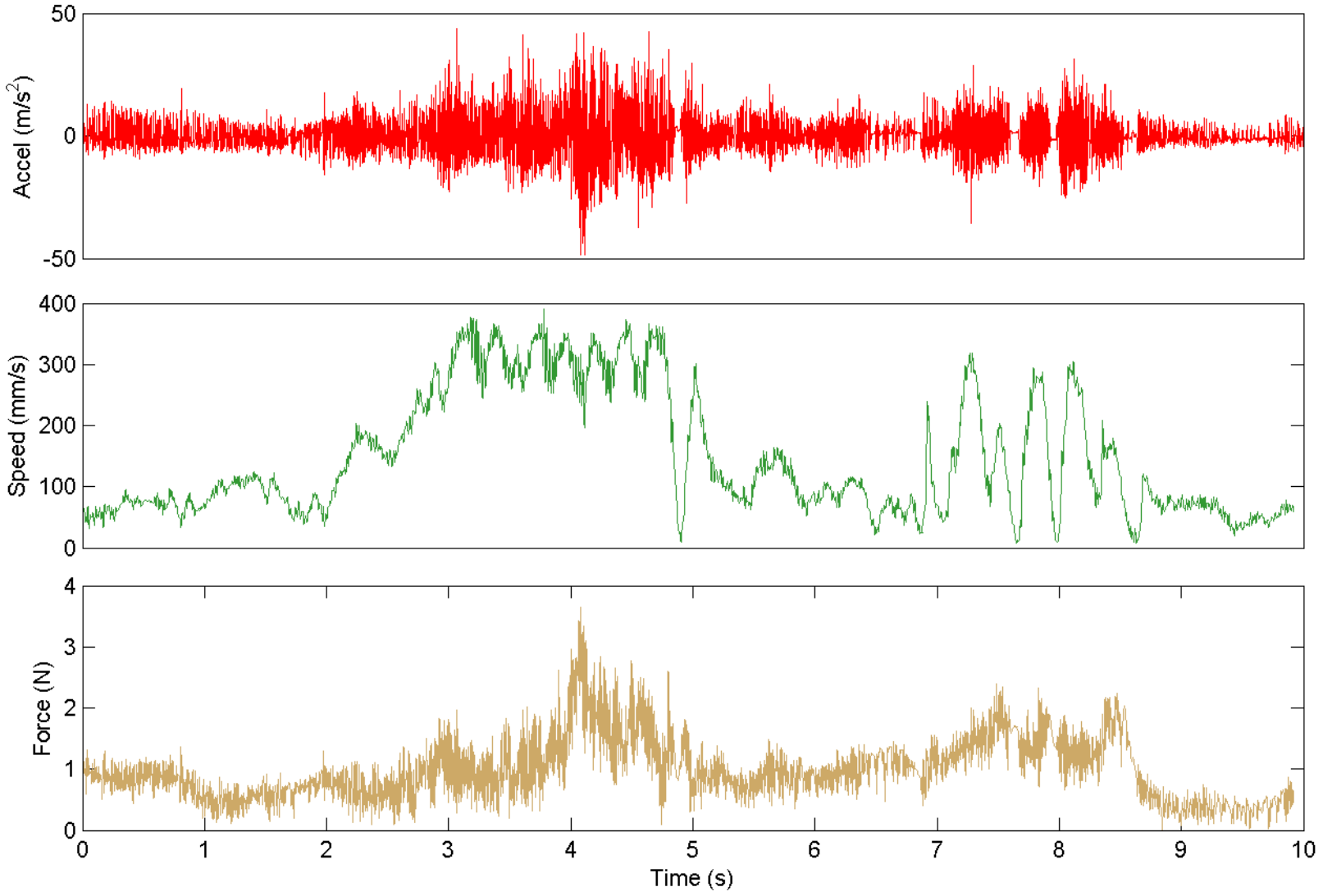
DATA-DRIVEN HAPTICS FOR INCREASED REALISM

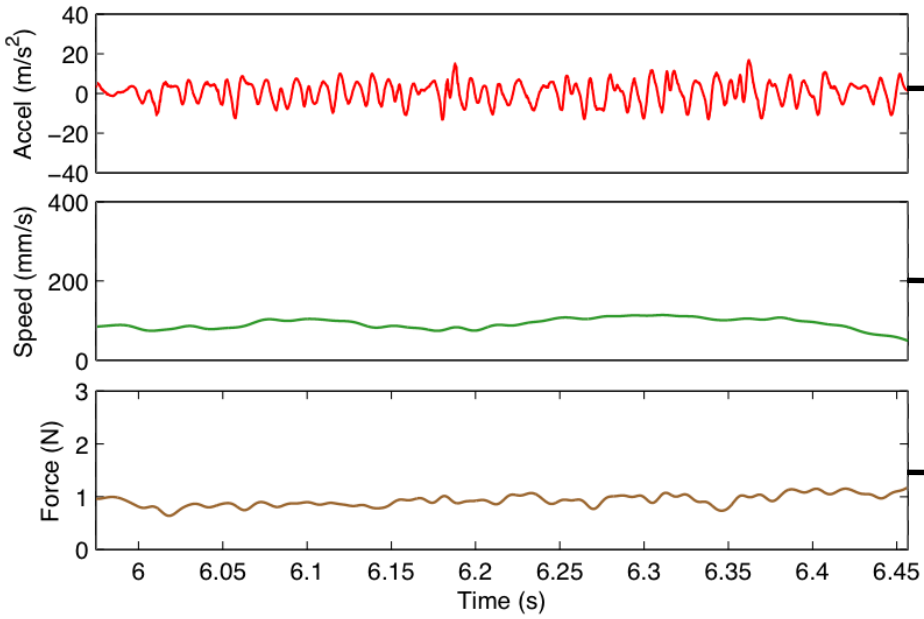
HAPTIC RECORDING DEVICE

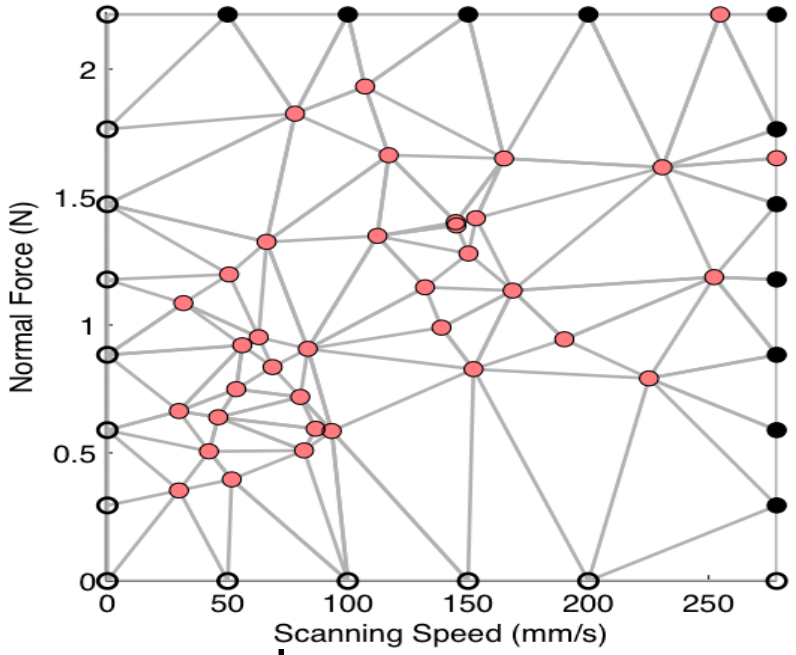



50
0
-50
Accel (m/s^2)
400
300
200
100
0
Speed (mm/s)
4
3
2
1
0
Force (N)
0
1
2
3
4
5
6
7
8
9
10
Time (s)

$$H(z) = \frac{1}{1 - \sum_{k=1}^{p} A_k z^{-k}}$$

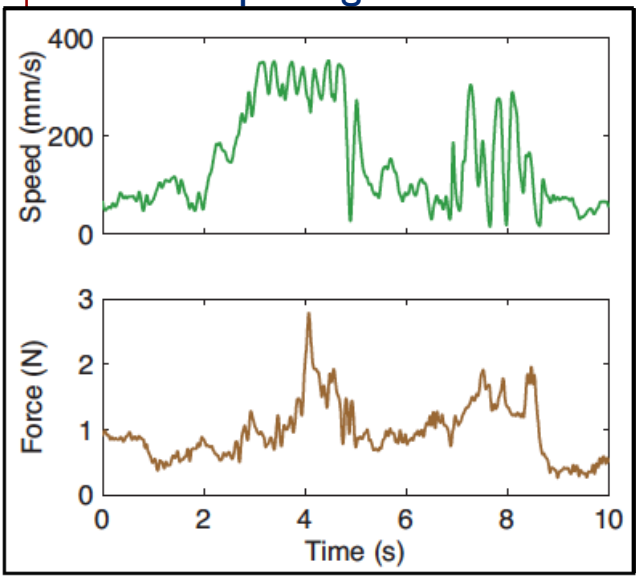
Autoregressive model





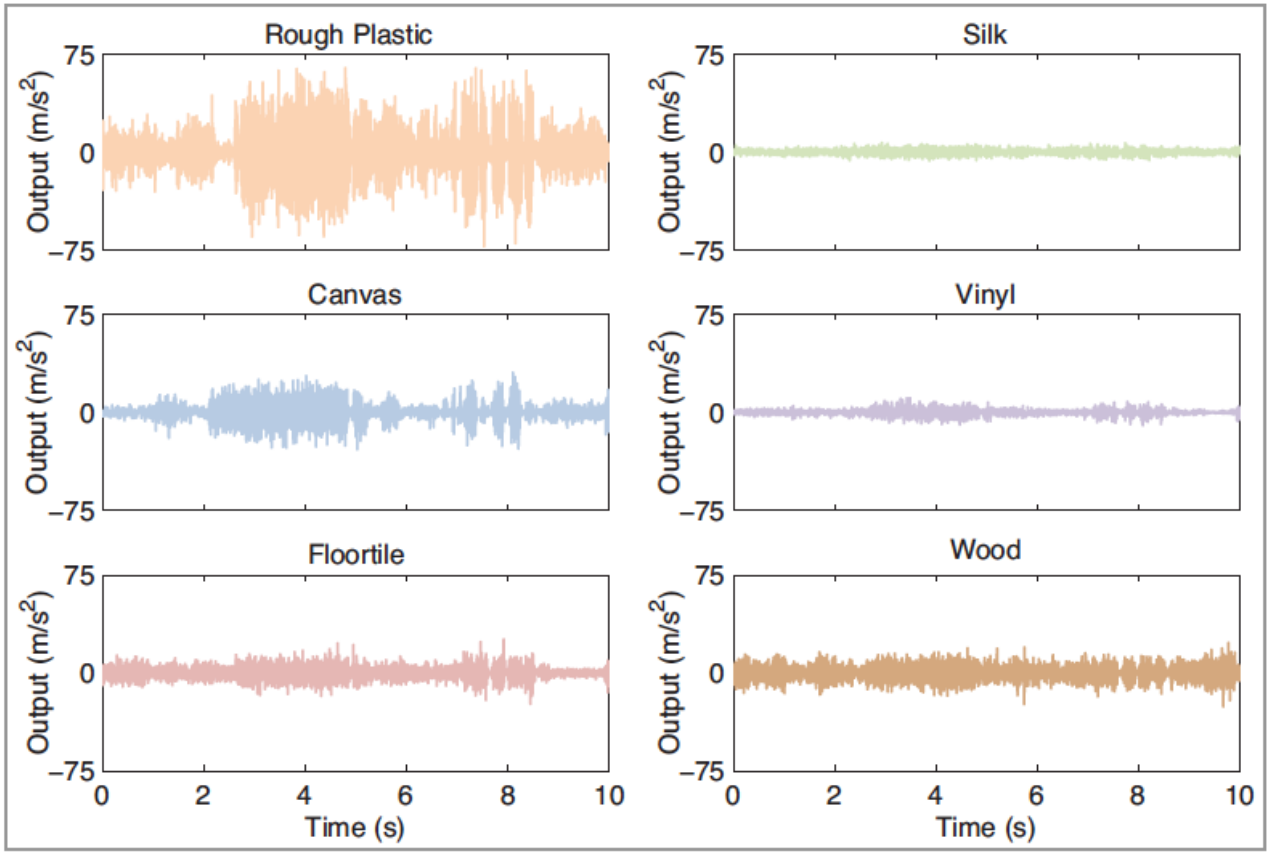
SYNTHESIZING A NEW TEXTURE OUTPUT

Input Signals



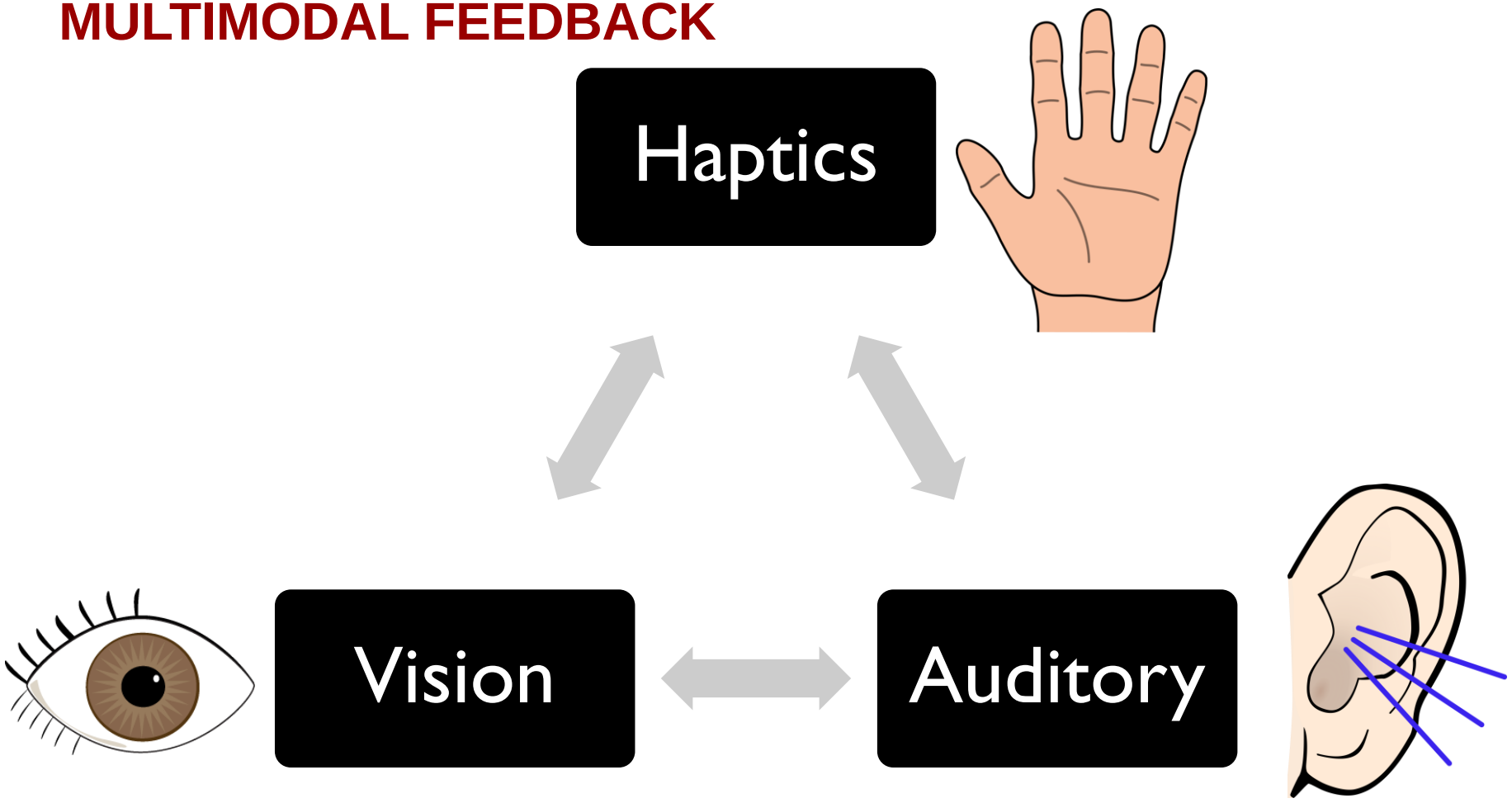
Recorded Data

Six Synthetic Texture Signals

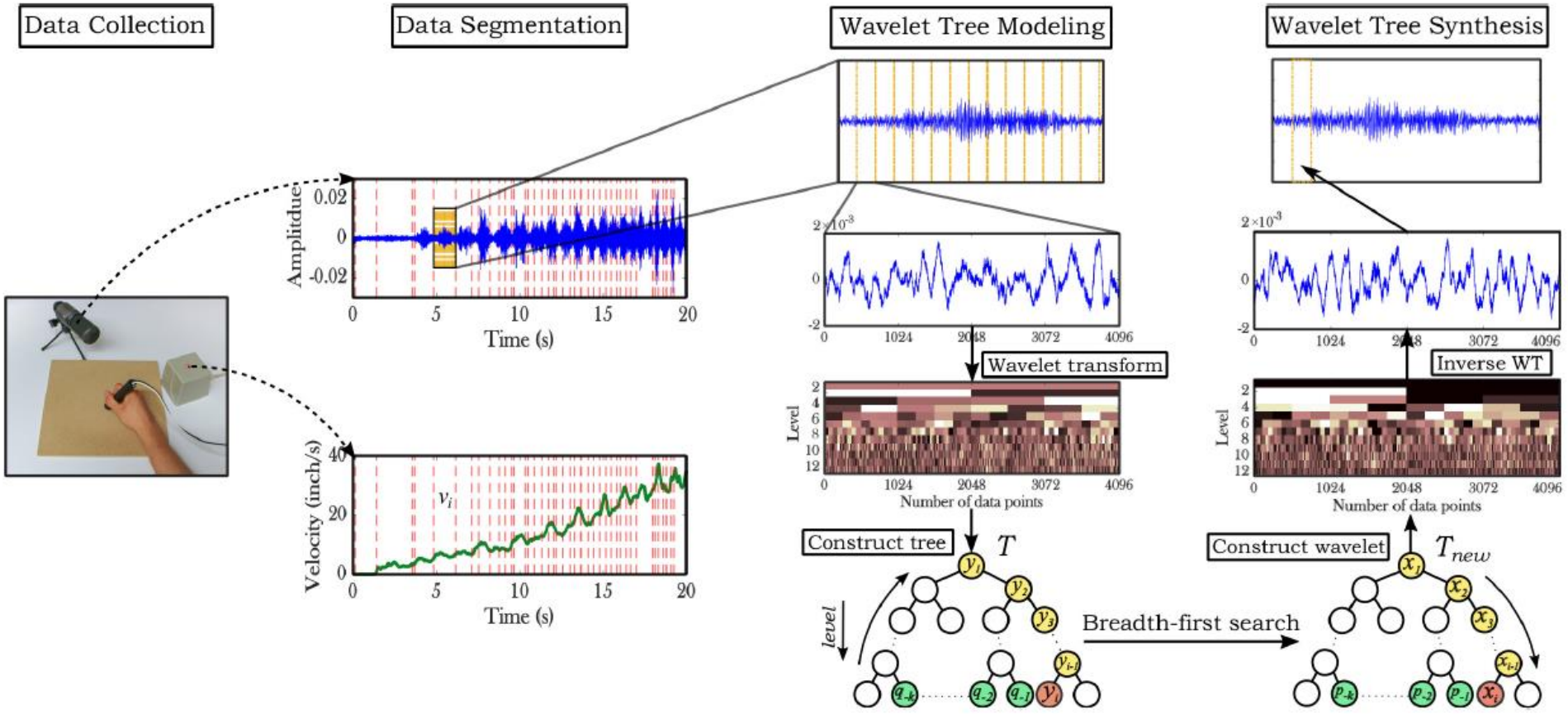


Synthesized Signals

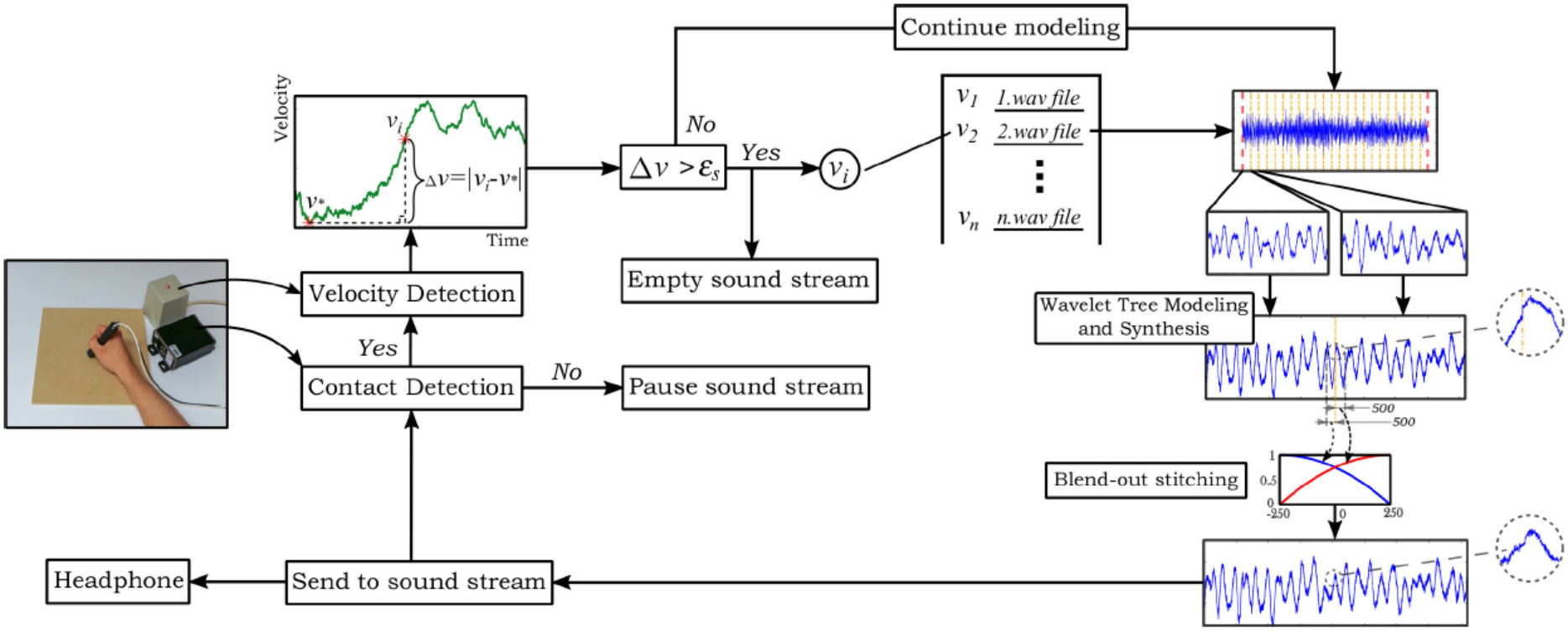
MULTIMODAL FEEDBACK



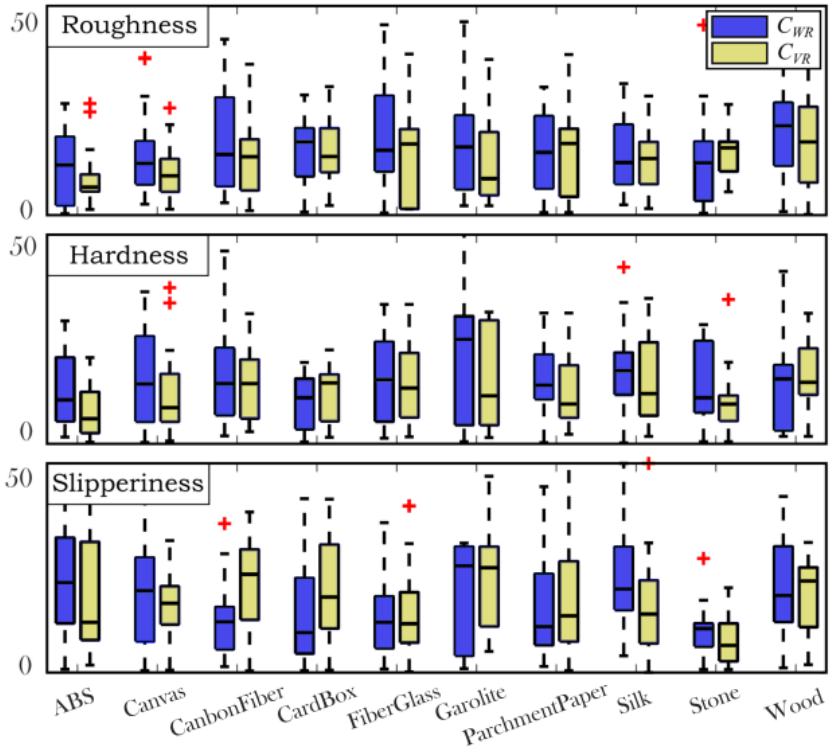
SOUND TEXTURE MODELING

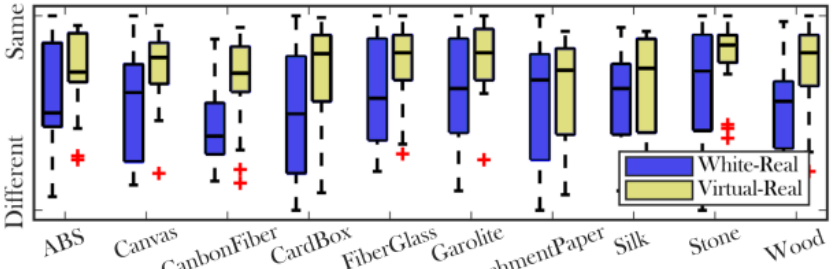


SOUND TEXTURE SYNTHESIS



RESULTS


Roughness
Hardness
Slipperiness
50
0
C_{WR}
C_{VR}
ABS
Canvas
CanbonFiber
CardBox
FiberGlass
Garolite
ParchmentPaper
Silk
Stone
Wood


Same
Different
White-Real
Virtual-Real
ABS
Canvas
CanbonFiber
CardBox
FiberGlass
Garolite
ParchmentPaper
Silk
Stone
Wood

USC Viterbi School of Engineering

HaRVI Lab

HARVI HAptics Robotics and Virtual Interaction Lab

Ph.D. Students
Sandeep George - CSCI
Shihan Lu – CSCI
Naghmeh Zamani – CSCI
Xin Zhu – CSCI

Master's Students
Nitu Sharaff – CSCI
Weicheng (Jerry) Wu – AME
Mansi Jaitly – CSCI

Undergrad Students
Alex Atcheson – CE
Yang Chen – CSCI
Kivilcim Cumbul – CSCI
Emiliia Dyrenkova – SURE student, BS CS at MiraCosta
Grant Garcia – ECE
Dustin Goetz – SURE student, BS ME at Ohio State
Pooja Moolchandari – CSCI
David Owusu-Antwi – SURE student, BS Physics at MIT
M'Kya Williams – REU student, BS CS at Westmont

THAT'S ALL!

Any Questions?