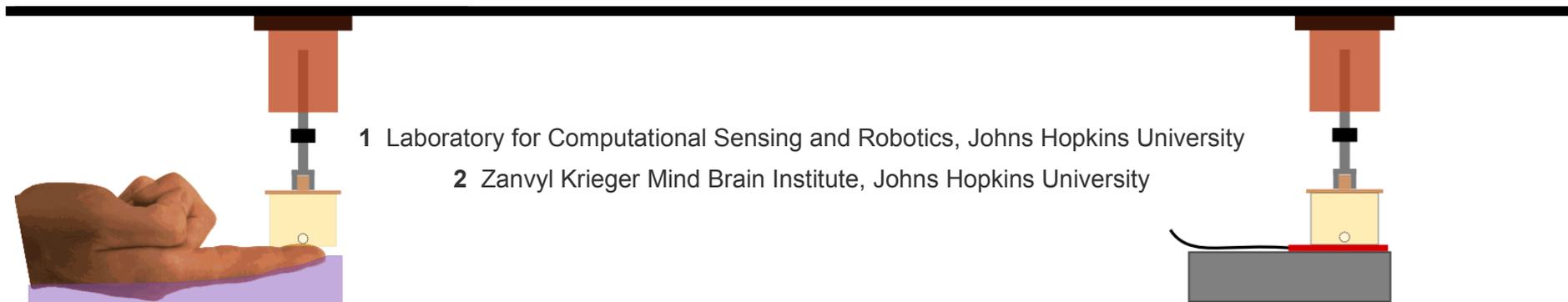# Human vs. Robotic Tactile Sensing: Detecting Lumps in Soft Tissue

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Allison M. Okamura [1], and Steven Hsiao [2]

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U N I V E R S I T Y

Motivation / Background

Natural Tactile Feedback

Motivation / Background

Natural Tactile Feedback

No Tactile Feedback

Motivation / Background

Natural Tactile Feedback → No Tactile Feedback → Artificial Tactile Feedback
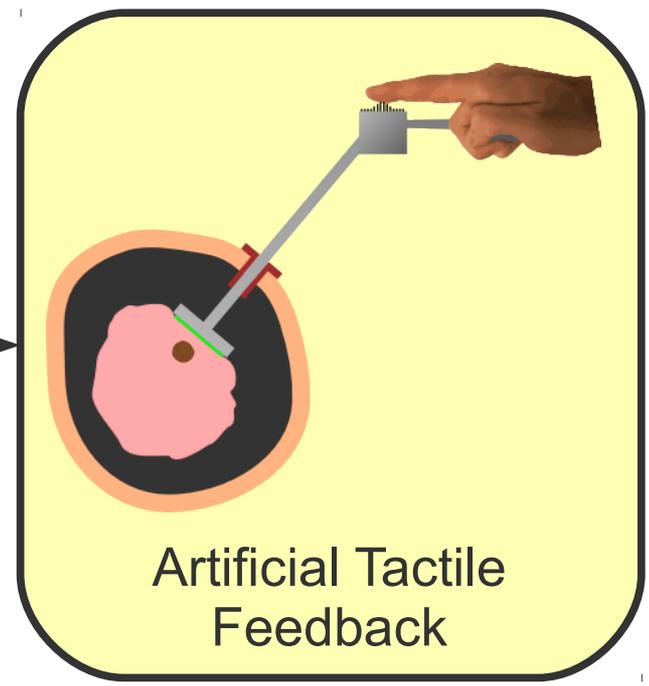
- Lump detection is Important in surgery

- Tactile information is required to detect lumps

Mechanical Displays
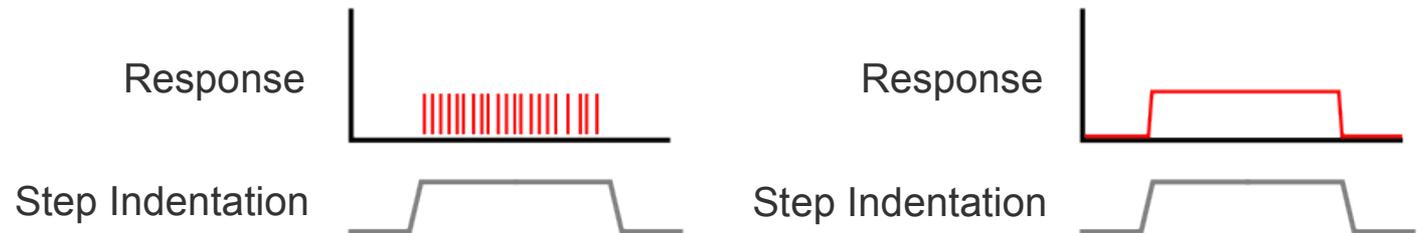- **Ottermo,** (Min Inv Ther, 2009)
- **Howe,** (ICRA, 1995)

Graphical Displays
- **Ramezanifard,** (Haptics Symp, 2008)
- **Trejos,** (BIOROB, 2008)
- **Egorov,** (IEEE Trans on Med Imag, 2008)
- **Miller,** (ICRA, 2007)
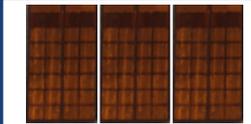- **Schostek,** (Min Inv Therapy, 2007)

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Human Finger vs. Tactile Sensor

	Response		Response
	Step Indentation		Step Indentation

|	Finger (SA I) [1, 2]	Tactile Sensor [3] (Pressure Profile Systems)
Sensing mechanism	Merkel Disks (neural)	capacitive
Density	~ 70 / cm^2	25 / cm^2
Spatial resolution	~ 1 mm	~ 2 mm
Sensing Area	~ 160 mm^2	285 mm^2

(1) K. Johnson and J. Phillips. Tactile spatial resolution. i. two-point discrimination, gap detection, grating resolution, and letter recognition. Journal of Neurophysiology, 46(6):1177–1192, 1981.
(2) J. Phillips and K. Johnson. Tactile spatial resolution. ii. neural representation of bars, edges, and gratings in monkey primary afferents. Journal of Neurophysiology, 46(6):1192–1203, 1981.
(3) DigiTacts II[TM] http://www.pressureprofile.com/UserFiles/File/DigiTactsII Evaluation/Specification Sheet.pdf

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Rubber Tissue Models

Ball (Lump) Size (mm)

Rubber **Hardness**

B

H
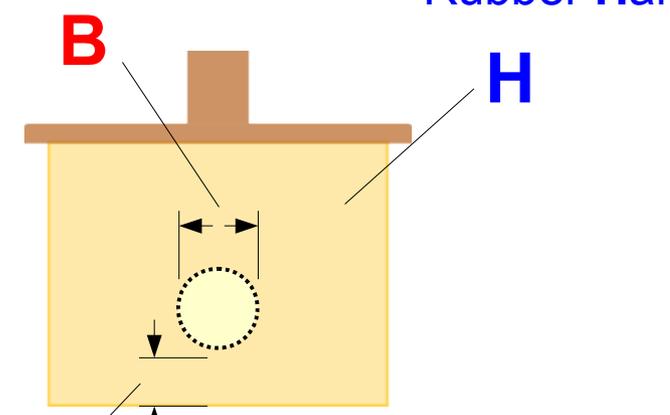
D

Depth below surface (mm)

25 mm

32 mm
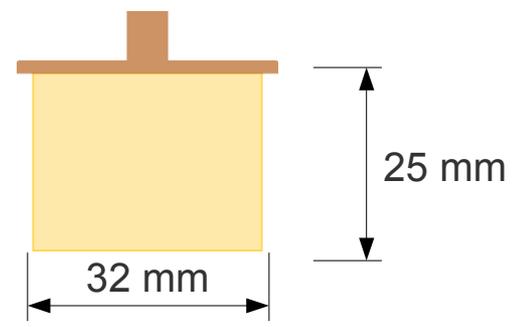
	00-10 (**H**10)			00-30 (**H**30)		
	B1	**B**2	**B**3	**B**1	**B**2	**B**3
(mm)	6.5	9.5	12.5	6.5	9.5	12.5
D1	1.5	1.5	1.5	1.5	1.5	1.5
D2	2.5	2.5	2.5	2.5	2.5	2.5
D3	3.5	3.5	3.5	3.5	3.5	3.5

SHORE 00

| 00-10 | 00-20 | 00-30 |

Extra Soft

Gummy Bear
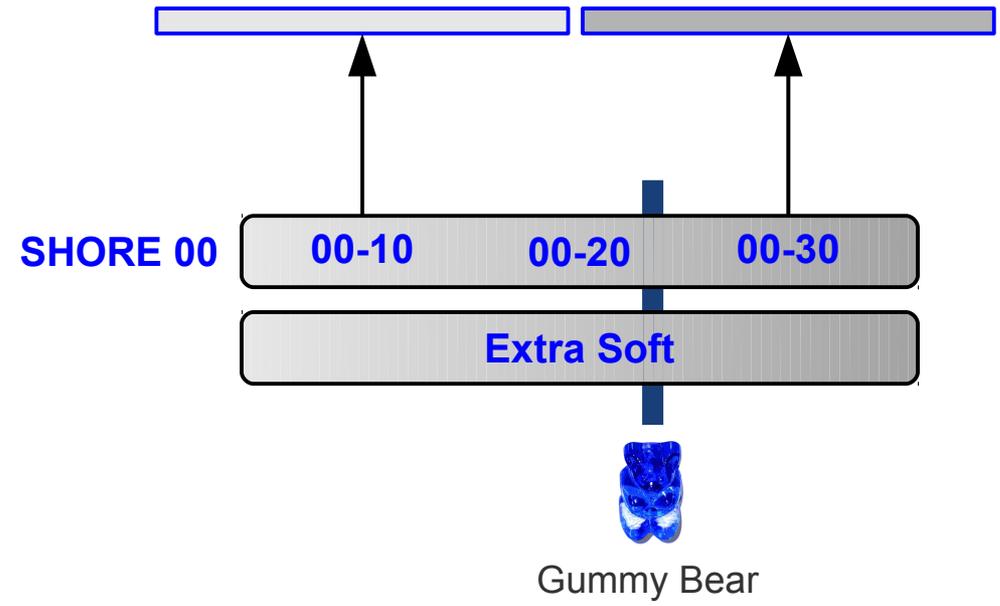
Stimulator

	Linear Motor (Vertical Motion)	Platen (Horizontal Motion)	Gripper
Travel (z)	40 mm	-	-
Travel (y)	-	1.2 m	-
Travel (x)	-	0.5 m	-
Resolution	1 μm	3 μm	0.05^o
Rotation	-	-	270°

- Forcer (mounted to platen)
- Air hose
- Linear motor
- Optical encoder
- Force sensor
- Stepper motor
- Gripper
- 100 mm
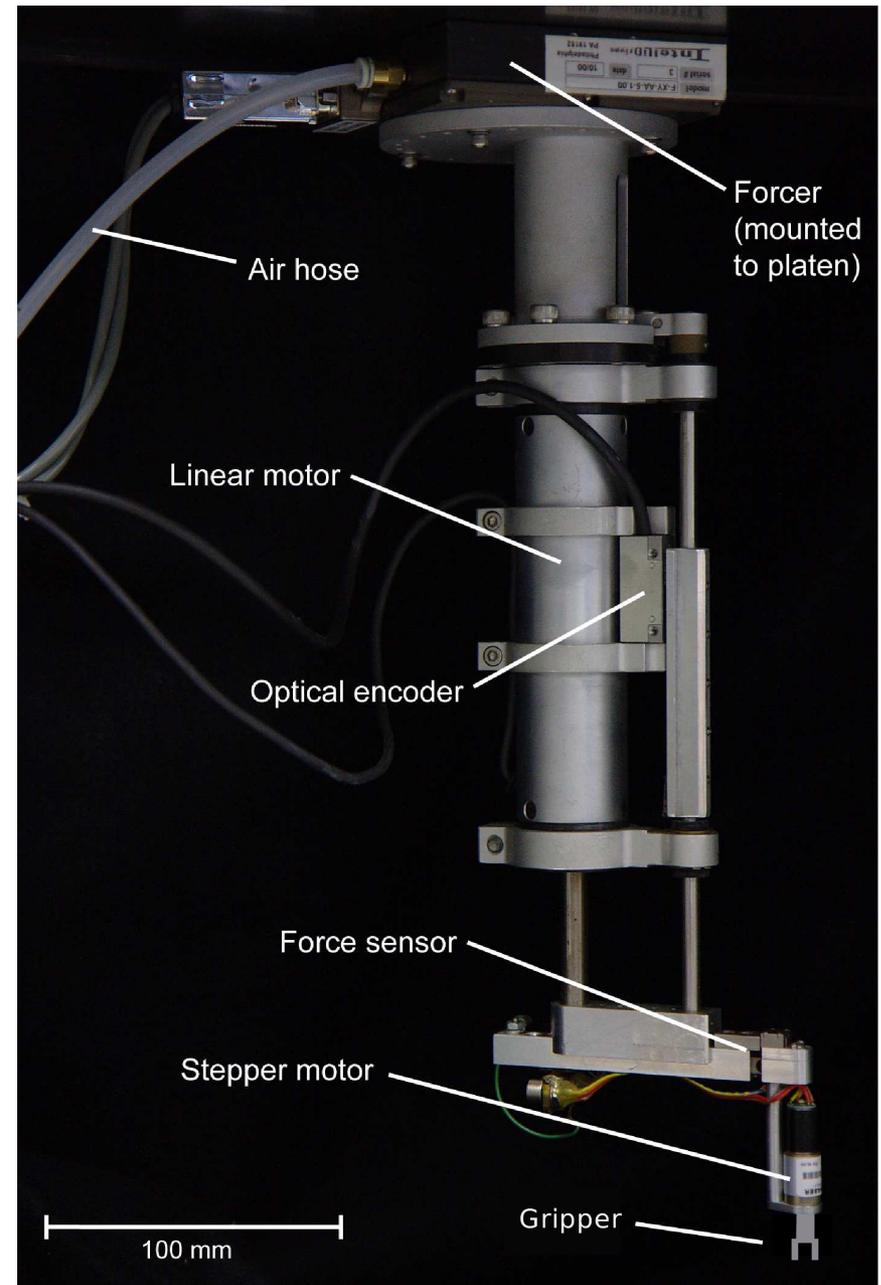
Tactile Sensor Protocol

| 0 mm | Break Contact | 0.25 mm | Break Contact | 0.5 mm |

Sensor Layout

1   2   3

12 mm

0.6
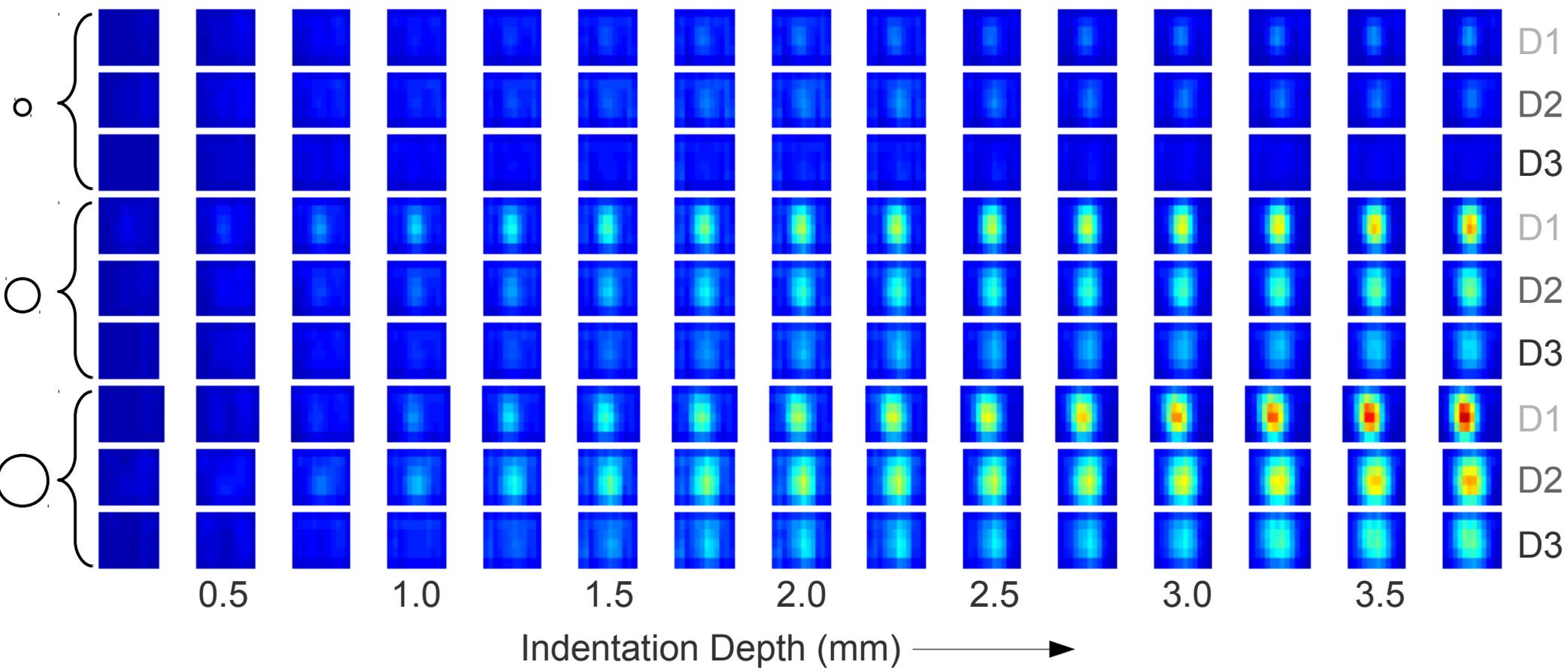8.5 mm

Sensor Output (V)
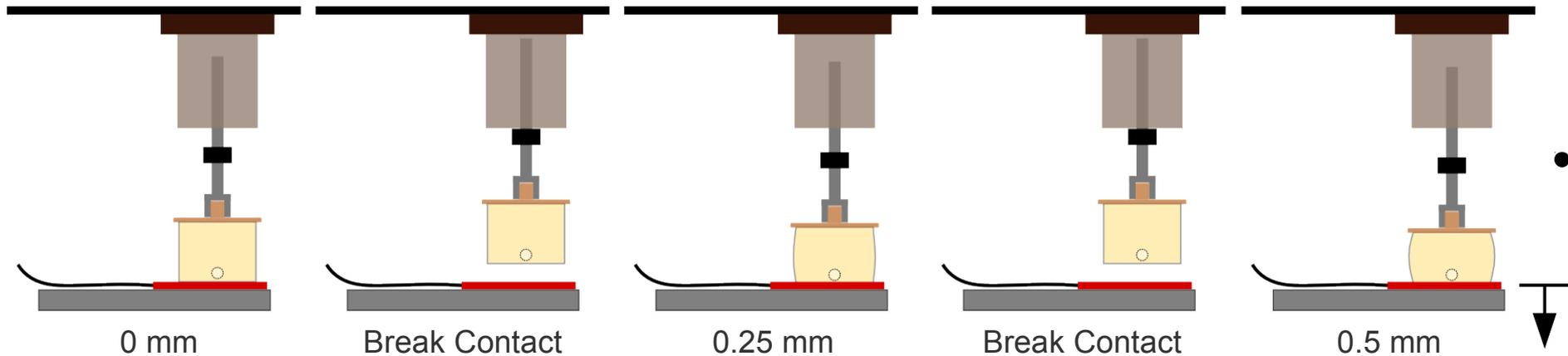
Indentation Depth (mm)
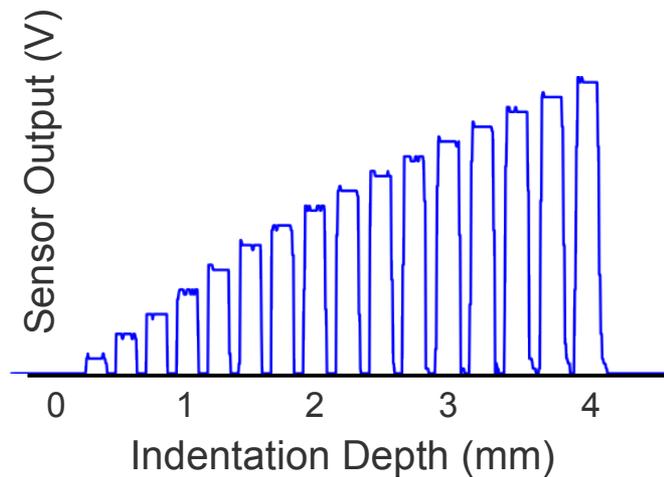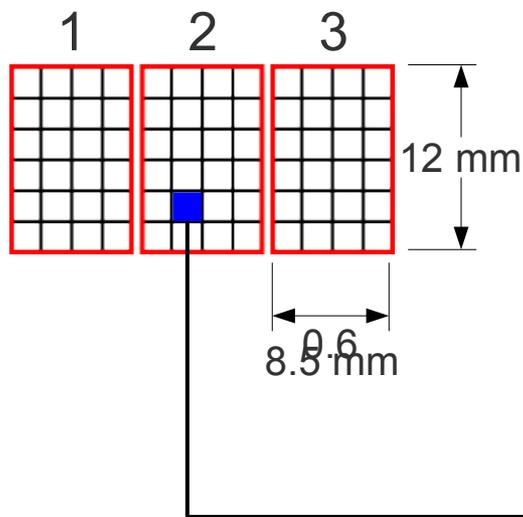
- Stimulator indents models into sensor from 0 to 4 mm in 0.25 mm increments

- Held at target depth for 250 ms

- Data used is from static portion of indentation (plateus at left)

Tactile Sensor Data

Indentation Depth (mm) →

Lump Diameter

B1 ∘ B2 ○ B3 ◯

6.5 mm   9.5 mm   12.5 mm

Lump Embedded Depth

D1 (1.5 mm)   D2 (2.5 mm)   D3 (3.5 mm)

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Characterizing Tactile Sensor Lump "Detection"

Step 1. Developing the Lump Model: What does a lump "look like" to the sensor?

All Images *with* Lumps
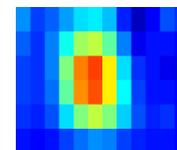
Normalize

Average Image **(Lump Class)**

All Images *without* Lumps

Normalize

Average Image **(No Lump Class)**

Difference Image

Fit Gaussian

"Lump Image" $\mathscr{L}$
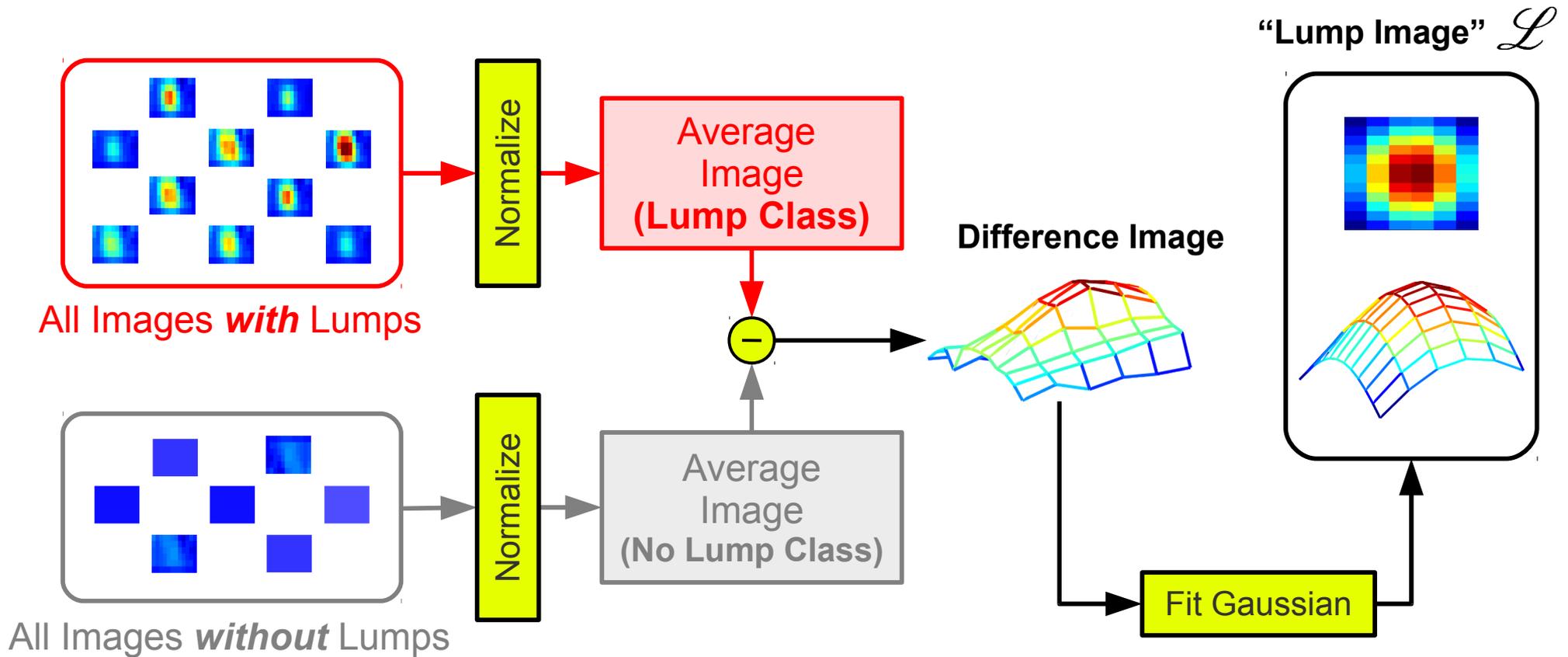
Characterizing Tactile Sensor Lump "Detection"

Step 2. Establish Correlation: How strongly is a lump detected for each tactile image?

$$L(I_i) = < I_i, \mathscr{L} >$$

Sum of pixel-wise multiplications between I_i and $\mathscr{L}$

I_i $\mathscr{L}$
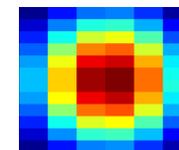
Each Image Lump Model

Step 3. Apply Thresholding: Does the classifier "detect" a lump based on the threshold?

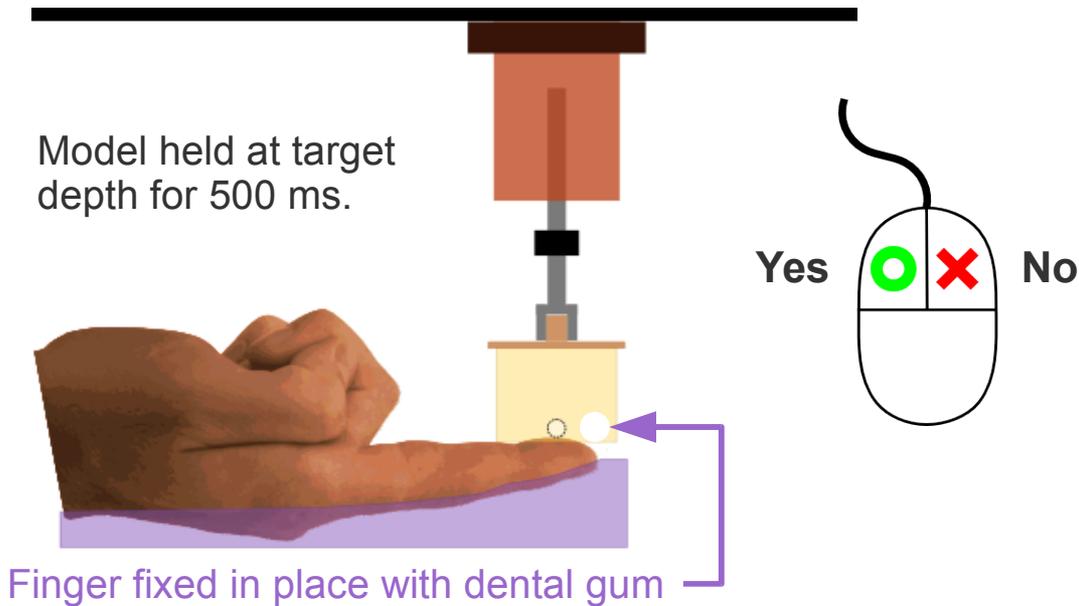$$D = \{i : L(I_i) > T\}$$

Set of images in which a lump is detected

T - **Threshold**

T is smallest value that gives no false positives

Human Psychophysics

Model held at target
depth for 500 ms.

Yes ⭕ ❌ **No**

Finger fixed in place with dental gum

"Staircase" Tracking Algorithm

X, Indentation depth (mm)

dB = 2   dB = 1 ¦ dB = 0.5

n ⟶

Reversal 1   Reversal 2

- Subjects trained with 5 models

- Initial indentation is random, below threshold

- **Trial ends when** last 10 indentations are within 2 dB

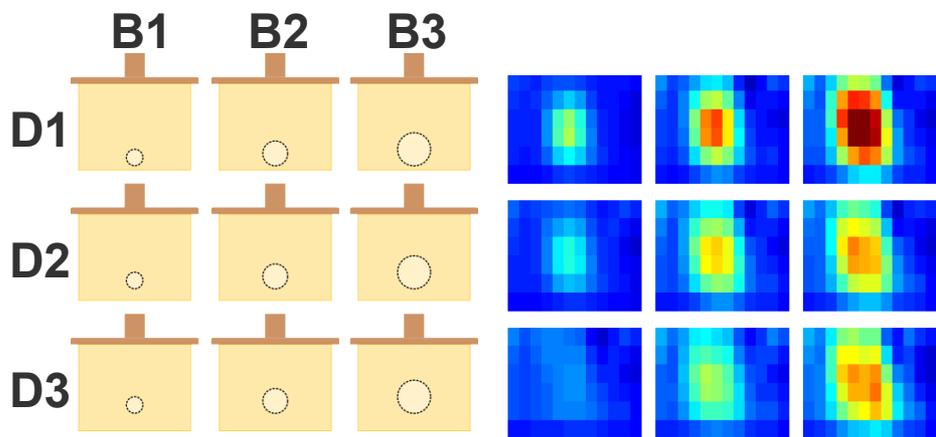- Indentation depth required for detection is mean of last five indentation values
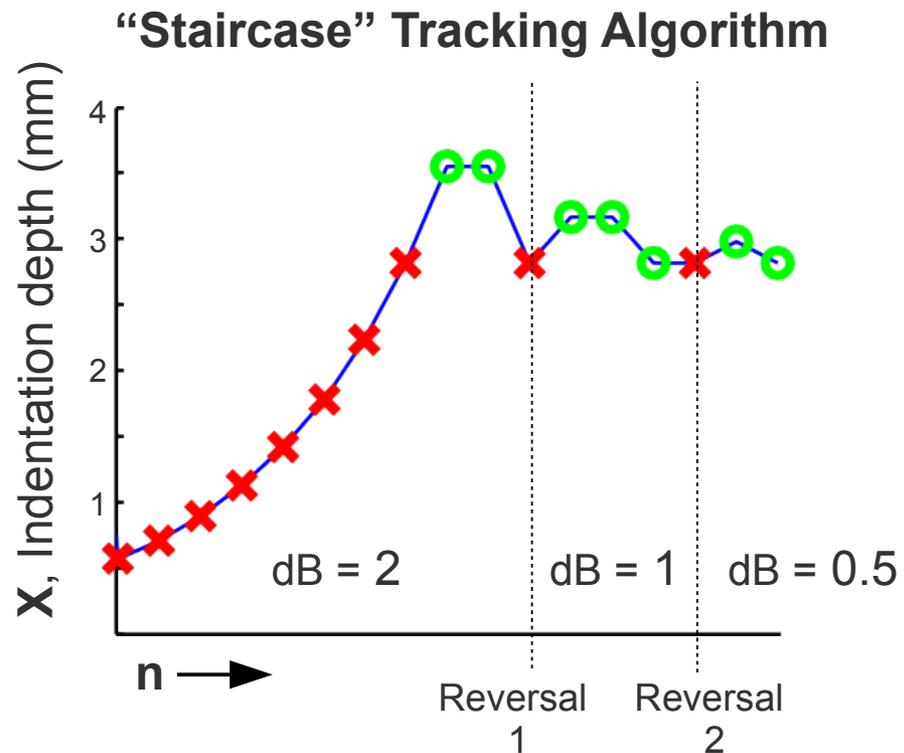
Indentation Depth defined by:

$$X_n = (X_{n-1}) \, 10^{\frac{dB}{20}}$$

Effects of Lump Size and Depth
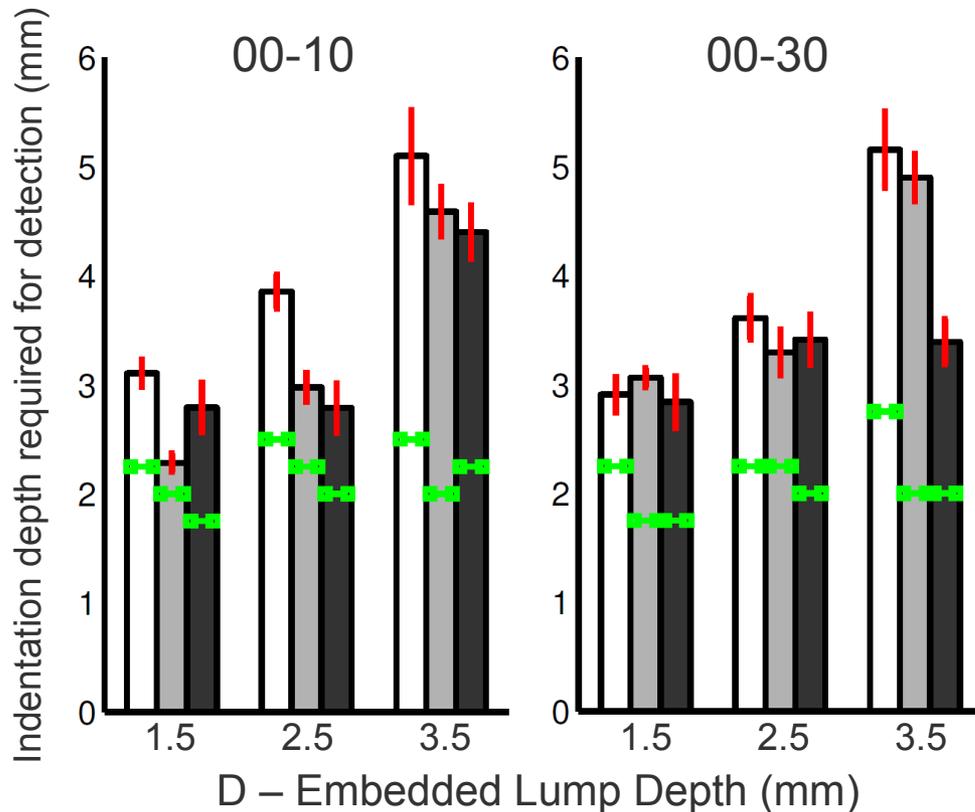
Indentation depth required for detection (mm)
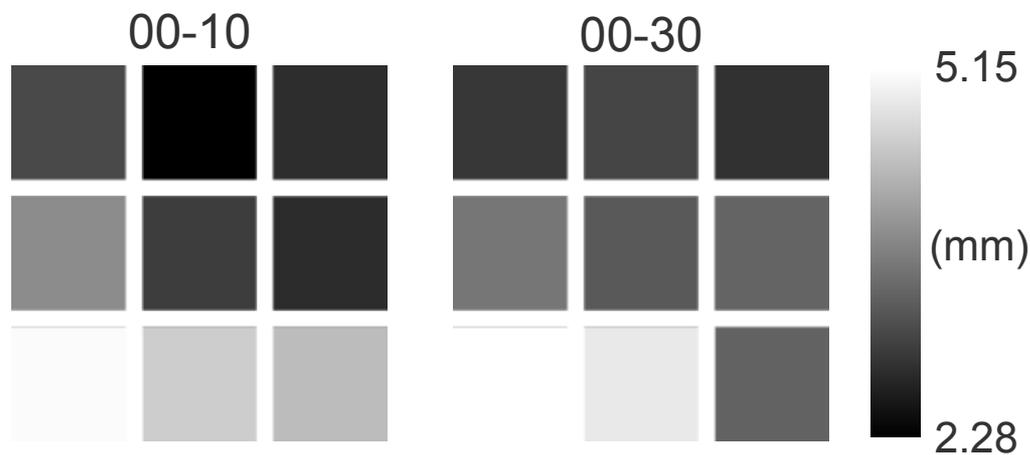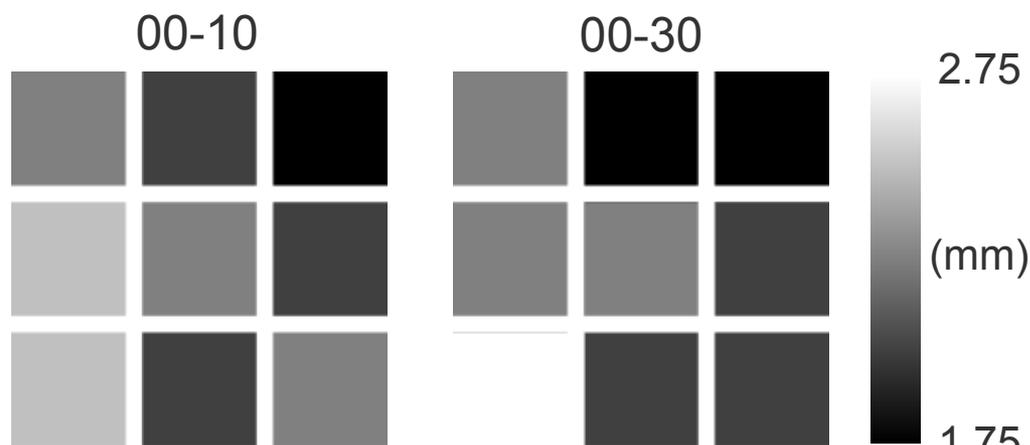
- Detectability of lumps increases as lumps lie closer to the exposed surface.

- Detectability of lumps increases with increasing lump size.

Human vs. Robot: Tactile Sensing Results

Tactile sensor outperforms finger.

- Uni-directional stimulus motion
- Sensor performance subject to tactile data processing methods and analysis

- Finger performance is more sensitive to embedded lump depth than sensor.

- Contrast in performance between sensor and finger is more significant at deeper lump depths.
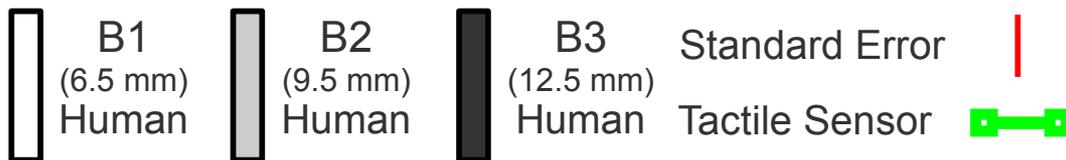
Data available at: **https://infrastructure.lcsr.jhu.edu/Tactile_sensors**

Current Work – Peripheral Nerve Recordings
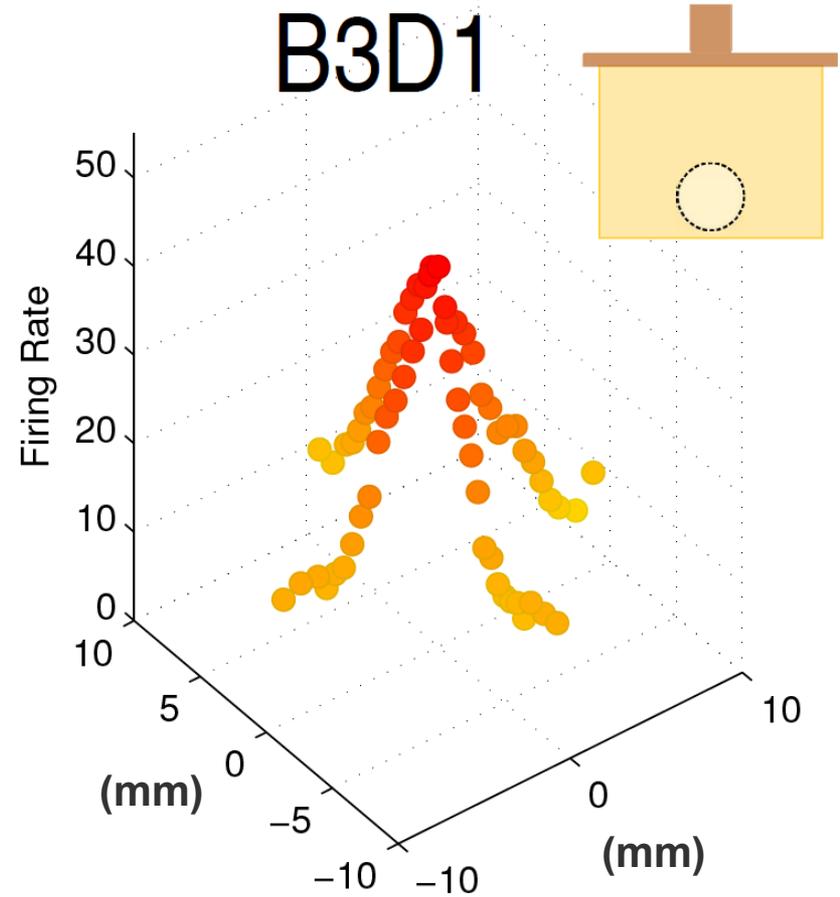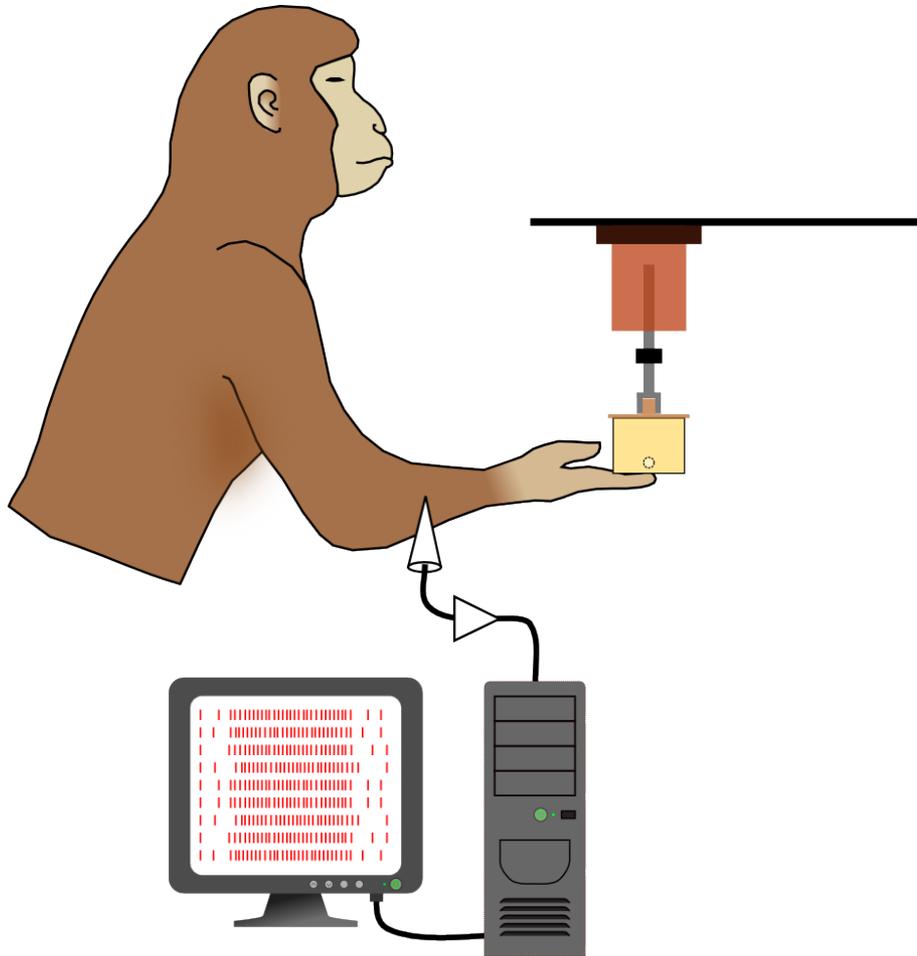
Acknowledgements

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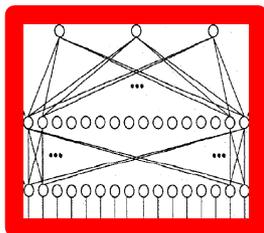
HIDDEN SLIDES

Artificial Tactile Sensing

1 **Tactile Sensing**

Dargahi, (Biomed Materials and Eng, 2004)
Ottermo, (Minimally Invasive Therapy, 2009)
Rao, (CCECE, 2003)
Schostek, (Minimally Invasive Therapy, 2006)
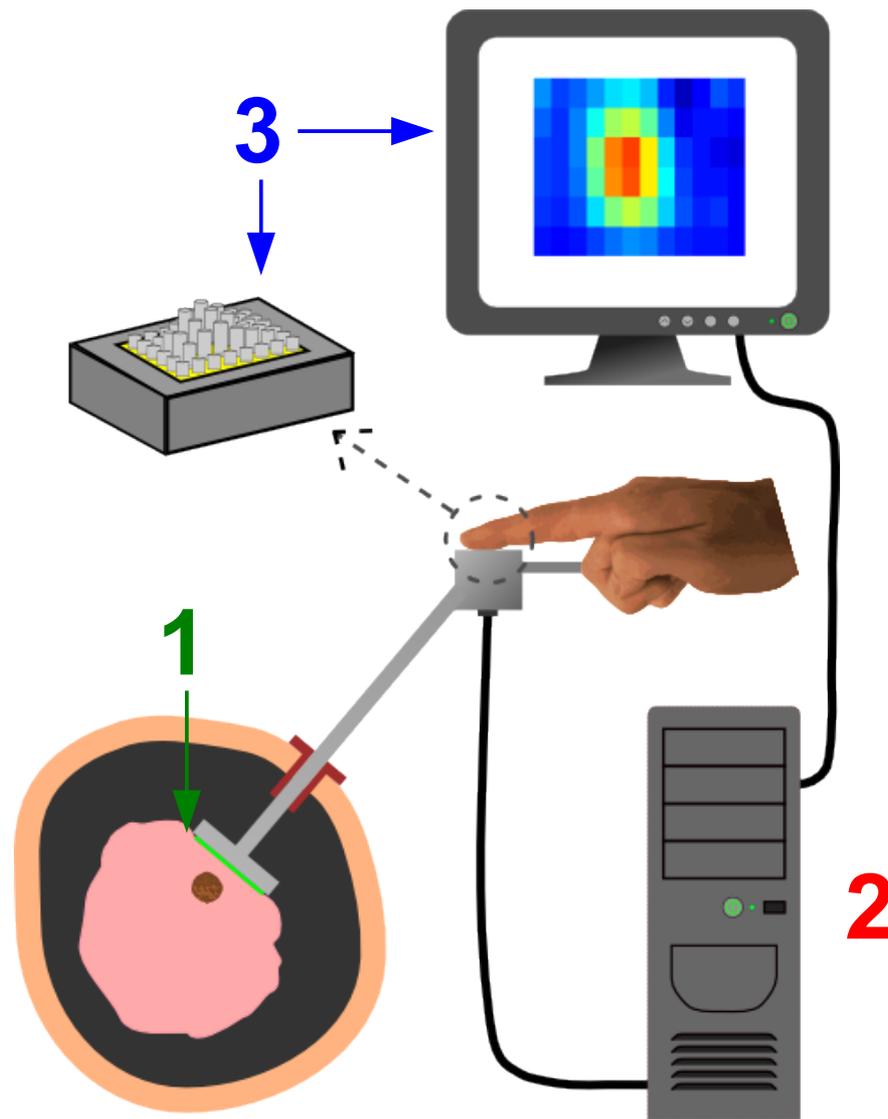
2 **Tactile Data Processing**

Chen, (IROS, 1995)
Charlton, (SMC, 1995)
Guo, (ICICIC, 2008)
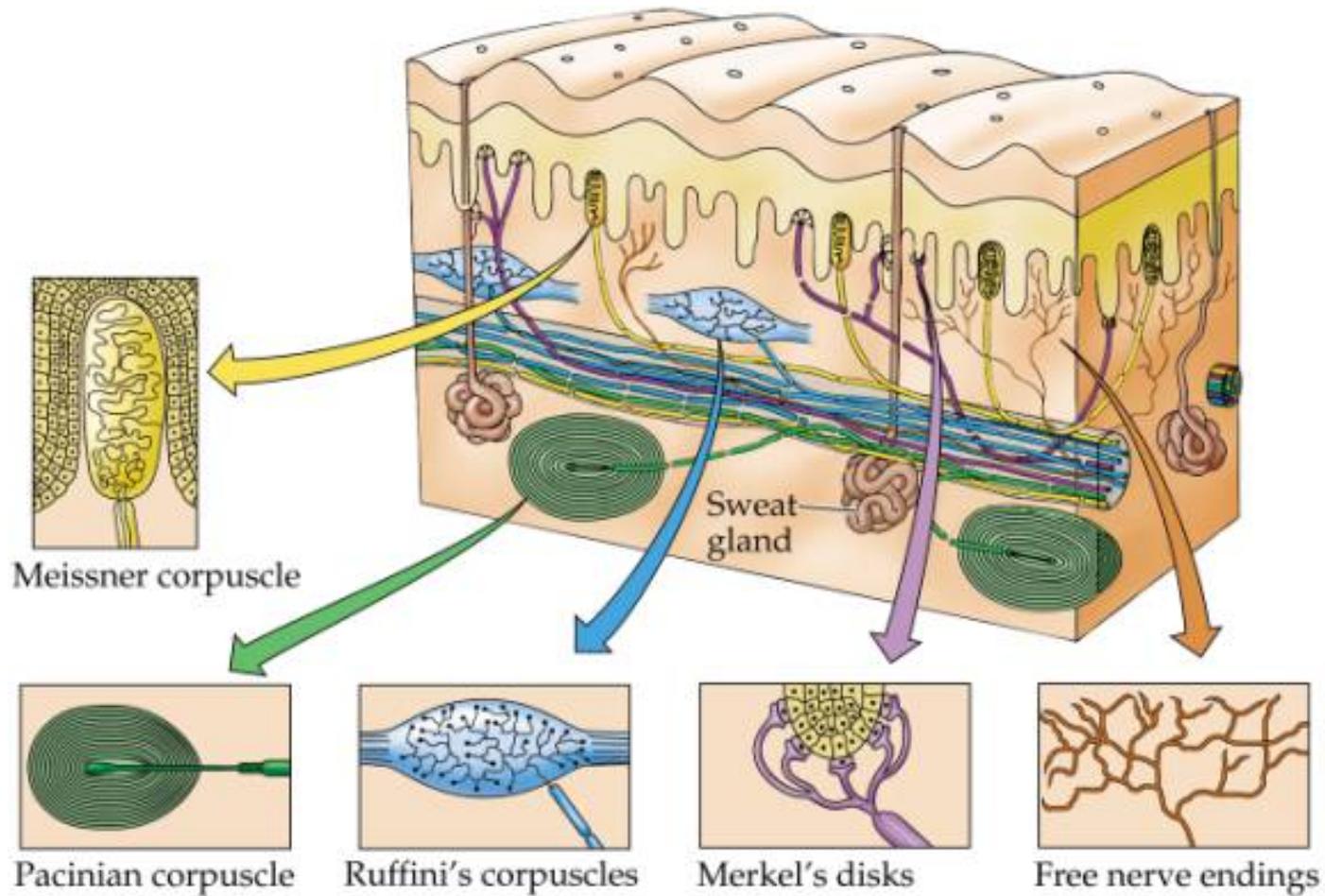Sarvazyan, (Trans on Med Imag, 2006,2008)

3 **Tactile Display**

Miller, (ICRA, 2007)
Ottermo, (Surg Lap End and Perc Tech, 2006)
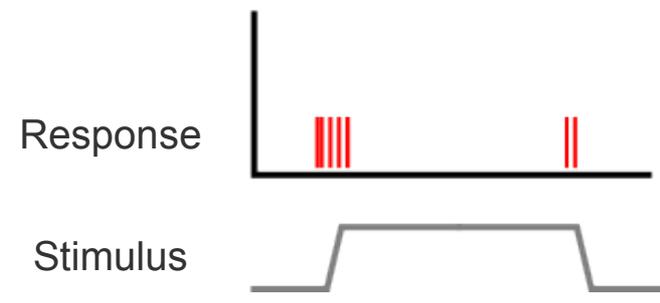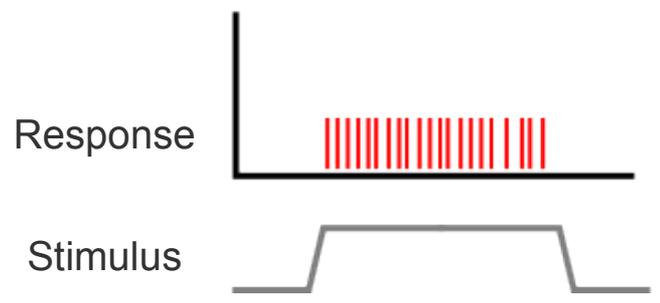Ottermo, (Haptics Symposium, 2005)
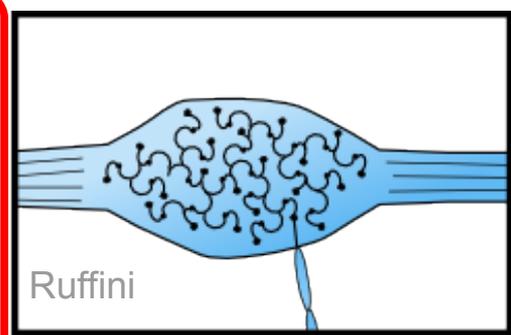Trejos, (BIOROB, 2008)

Mechanoreceptors

Meissner corpuscle

Sweat gland

Pacinian corpuscle

Ruffini's corpuscles

Merkel's disks

Free nerve endings

Finger Mechanoreceptors

Response

Stimulus

Response

Stimulus

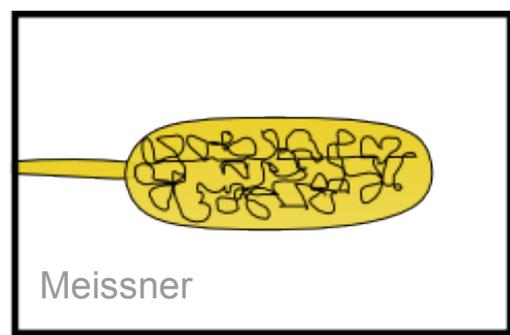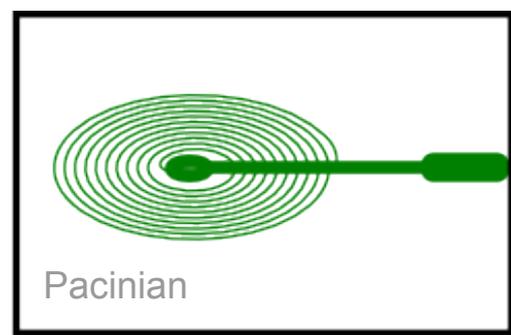| Merkel	Ruffini	Meissner	Pacinian
SA I	**SA II**	**RA**	**PC**
- Form and Texture perception - Low Frequency Vibrations	- Static and Dynamic Skin Deformation - Skin Stretch	- Motion, Slip/Grip - Dynamic Skin Deformation	- High Frequency Vibration - Gross pressure changes