

Visually Estimating Contact Pressure for Humans and Robots



Charlie Kemp

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Charlie's Conflict of Interest Statement

Dr. Kemp is both an associate professor at Georgia Tech and the chief technology officer (CTO) of Hello Robot Inc. where he works part time. **He owns equity** in Hello Robot Inc. and is an inventor of Georgia Tech intellectual property (IP) licensed by Hello Robot Inc. Consequently, **he receives royalties** through Georgia Tech for sales made by Hello Robot Inc. He also benefits from increases in the value of Hello Robot Inc.

Summary: If Hello Robot does well, Charlie does well.

A Collaborative Effort



PhD Students



Samarth
Brahmhatt
contributing postdoc at 



Henry
Clever



Patrick
Grady

Master's Students



Cusuh
Ham



Jeremy
Collins

Faculty



James
Hays



Charlie
Kemp



Greg
Turk



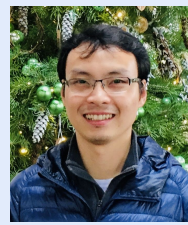
Chengcheng
Tang



Christopher
Twigg



Chengde
Wan



Minh
Vo

PressureVision: Estimating Hand Pressure from a Single RGB Image, Patrick Grady, Chengcheng Tang, Samarth Brahmhatt, Christopher D. Twigg, Chengde Wan, **James Hays**, **Charles C. Kemp**, European Conference on Computer Vision (ECCV) 2022.

Visual Pressure Estimation and Control for Soft Robotic Grippers, Patrick Grady, **Jeremy A. Collins**, Samarth Brahmhatt, Christopher D. Twigg, Chengcheng Tang, **James Hays**, **Charles C. Kemp**, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2022.



Patrick Grady



Jeremy Collins



James Hays



Charlie Kemp

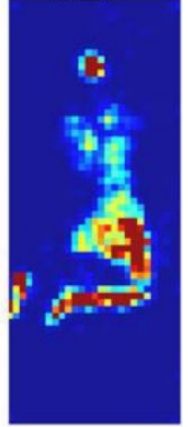
Visually Estimating **Contact Pressure** for Humans and Robots

Pressure resulting from surfaces in contact

A hand manipulating an object

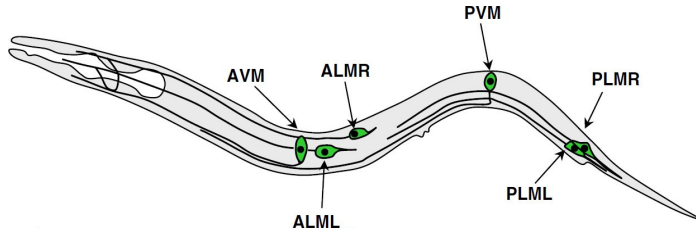
A robot assisting a person

A person resting their body

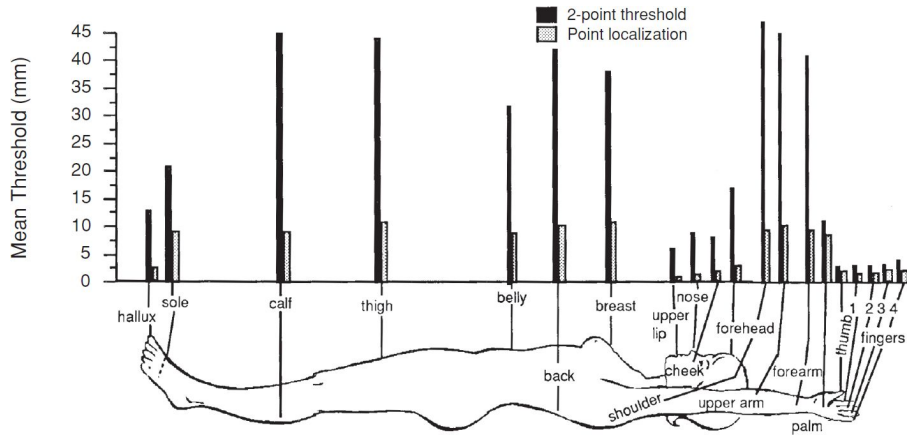


Visually Estimating Contact Pressure for Humans and Robots

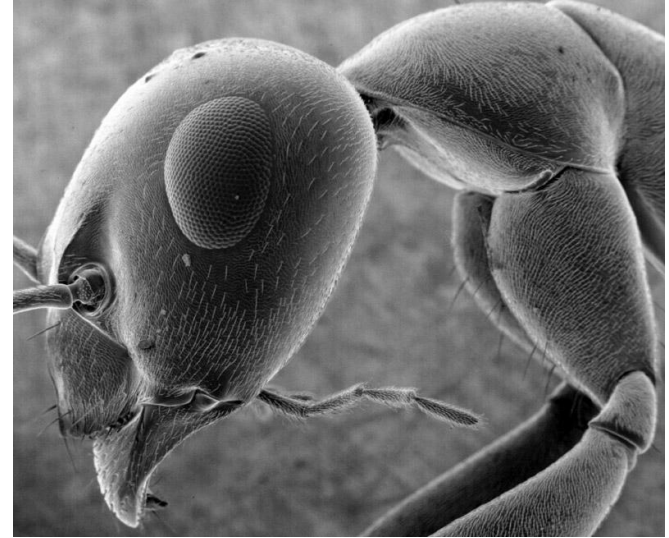
Biological Organisms Sense Contact Pressure



Nematode (~mm)



Human (~m)



Ant (~cm)

[image of nematode] Bianchi L, *Mechanotransduction: Touch and feel at the molecular level as modeled in caenorhabditis elegans*. *Molecular Neurobiology* 36(3): 254–271, 2007.

[image of ant] from the Dartmouth College Electron Microscope Facility, <http://remf.dartmouth.edu/images/insectPart3SEM/source/31.html>

[image of human] Lederman, Susan J., and Roberta L. Klatzky. *Haptic perception: A tutorial*. *Attention, Perception, & Psychophysics* 71.7, 1439-1459, 2009.

Covering Surfaces with Physical Sensors

Alters contact mechanics

Subjects sensors to wear

Requires sensing at many locations



<https://pressureprofile.com/body-pressure-mapping/tactile-glove>



<https://thewire.in/the-sciences/meet-the-archaeologists-chiseling-stone-tools-to-learn-how-our-forebears-did-it>



Tapomayukh Bhattacharjee, Advait Jain, Sarvagya Vaish, Marc D. Killpack, and Charles C. Kemp, *Tactile Sensing over Articulated Joints with Stretchable Sensors*, IEEE World Haptics Conference (WHC 2013), 2013.

Visually Estimating Contact Pressure

Unaltered contact mechanics

Robust, mature, low-cost sensors

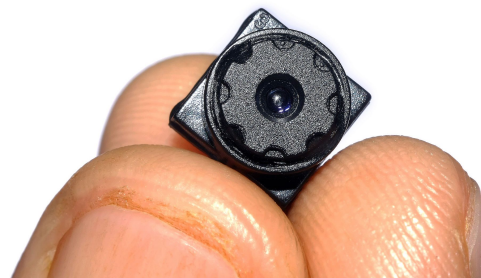
Scales to large surfaces



<https://upload.wikimedia.org/wikipedia/commons/3/32/Human-Hands-Front-Back.jpg>

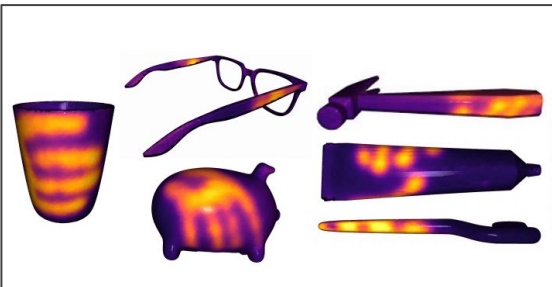


<https://thewire.in/the-sciences/meet-the-archaeologists-chiseling-stone-tools-to-learn-how-our-forebears-did-it>

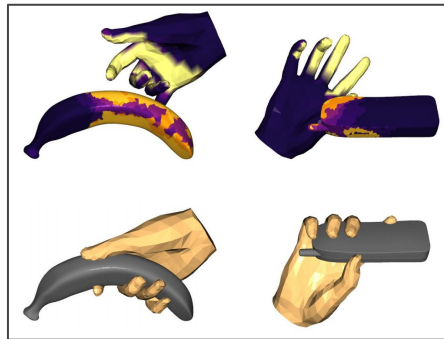


https://en.wikipedia.org/wiki/Hidden_camera#/media/File:Lens_of_Mini_Camcorder.jpg

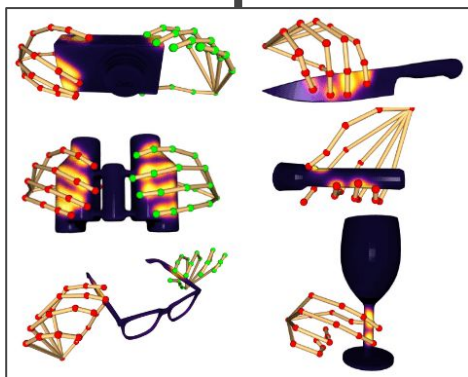
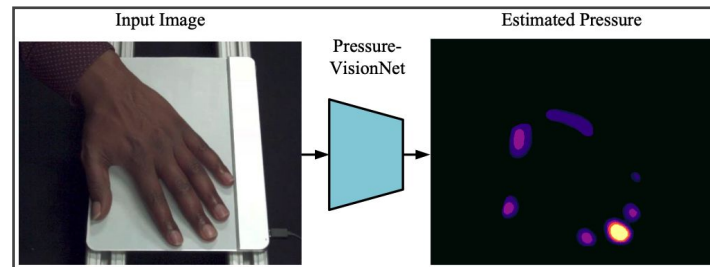
[Brahmbhatt et al](#)
[CVPR '19 \(oral\)](#)
[Best Paper finalist](#)



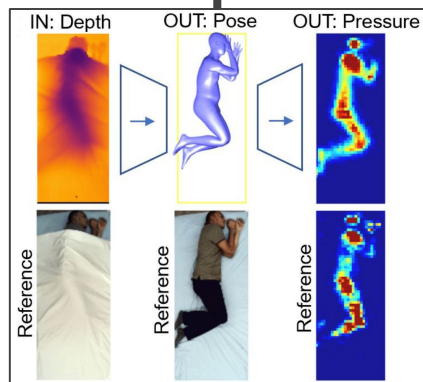
[Grady et al](#)
[CVPR '21 \(oral\)](#)



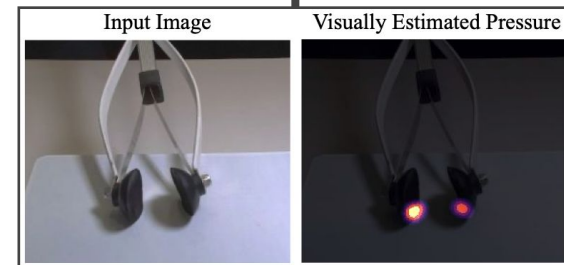
[Grady et al](#)
[ECCV '22 \(oral\)](#)



[Brahmbhatt et al](#)
[ECCV '20](#)

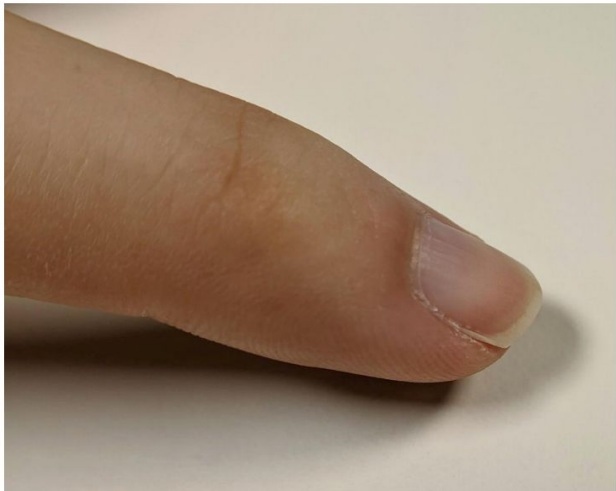


[Clever et al](#)
[PAMI '22](#)



[Grady et al](#)
[IROS '22](#)

No Contact



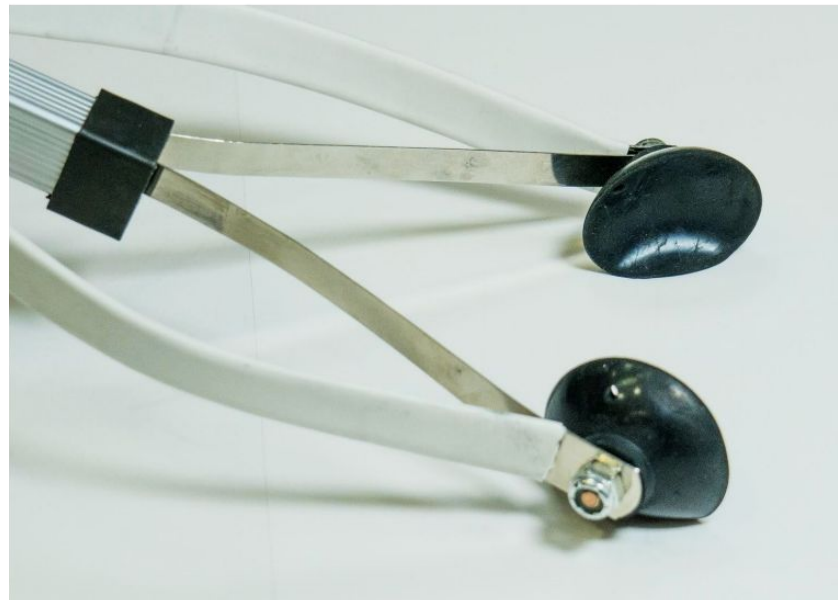
Low Force

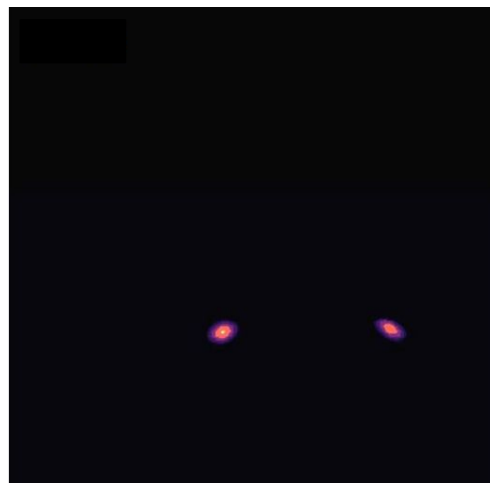


High Force









Input Image

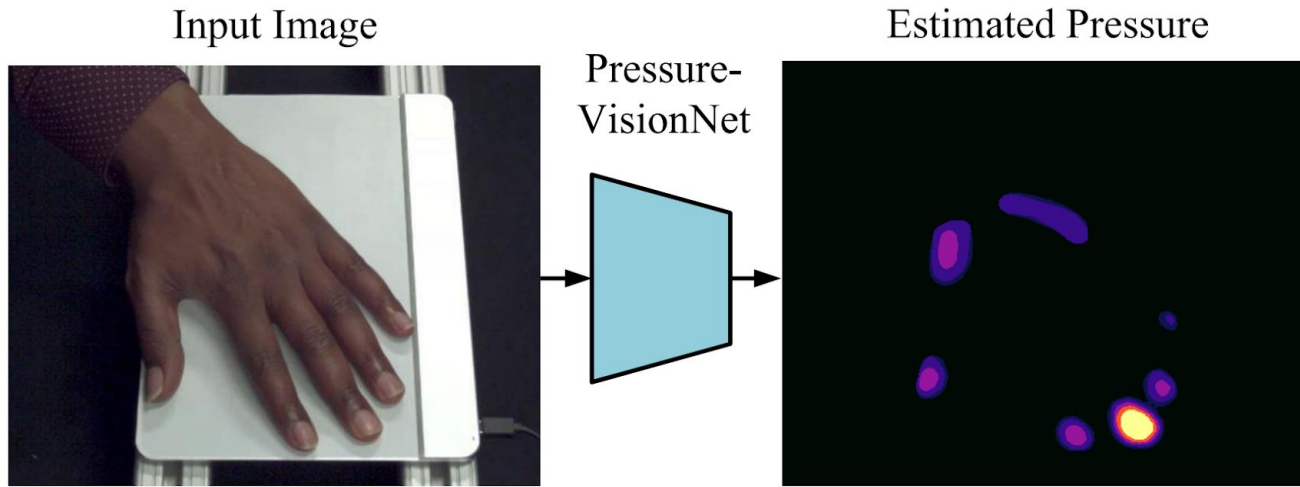


Visually Estimated Pressure



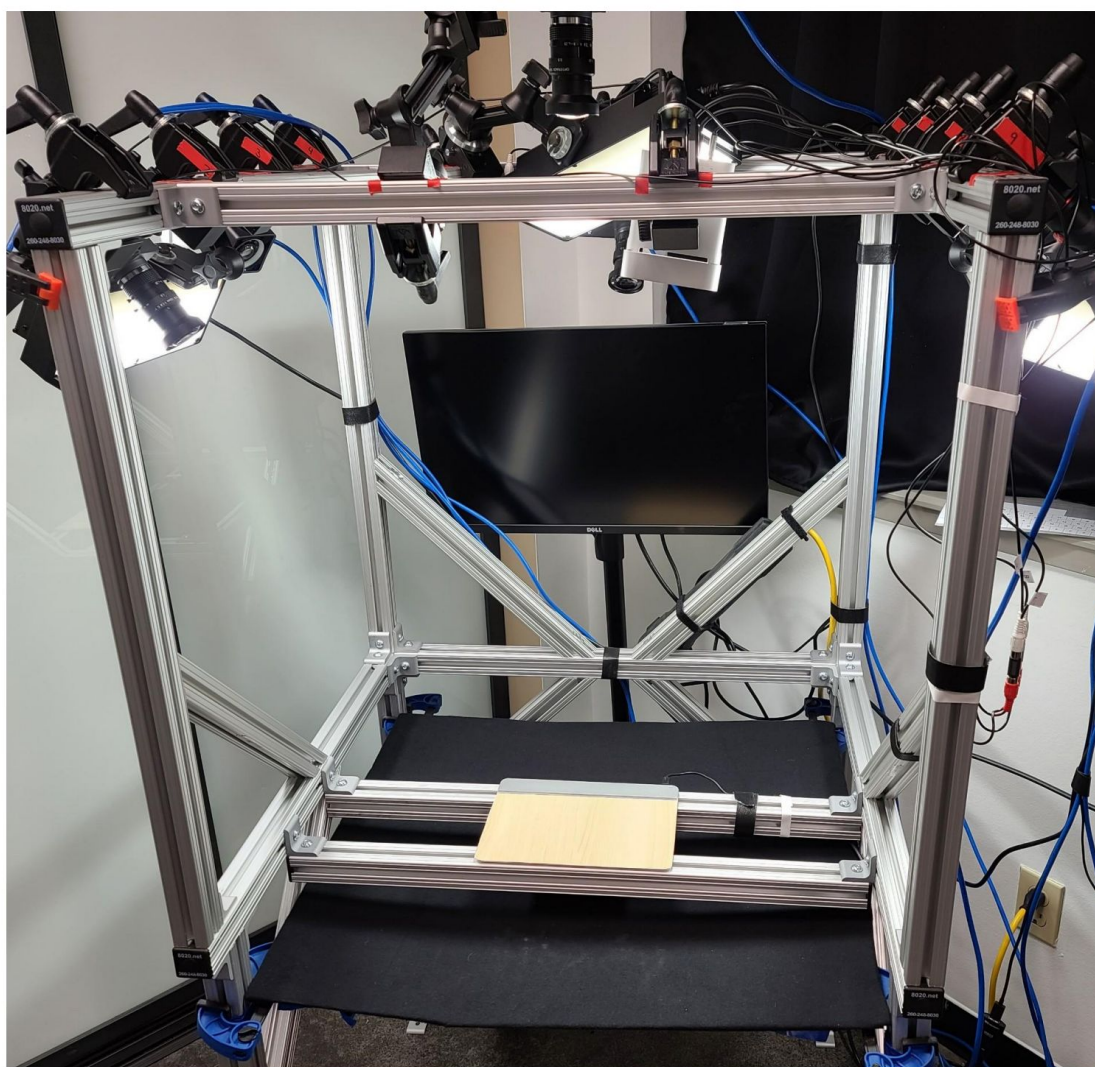
Ground Truth Pressure



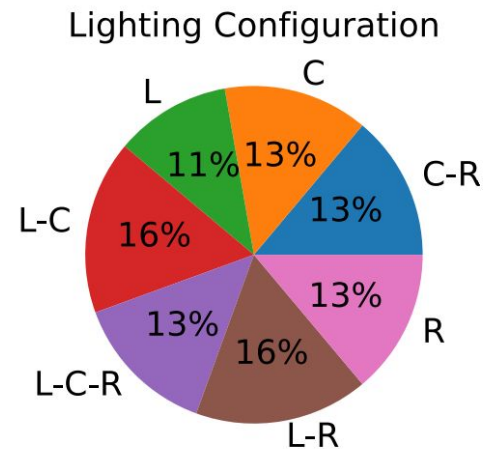
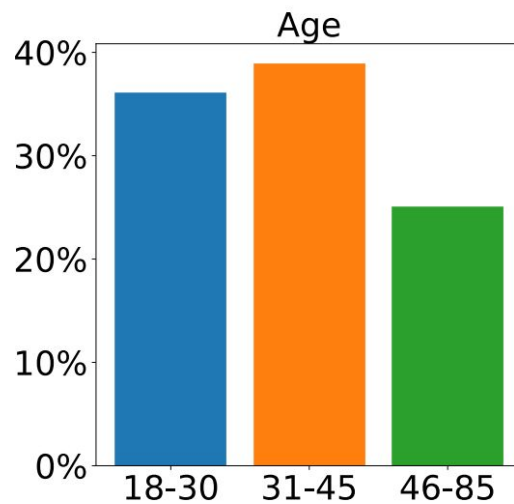
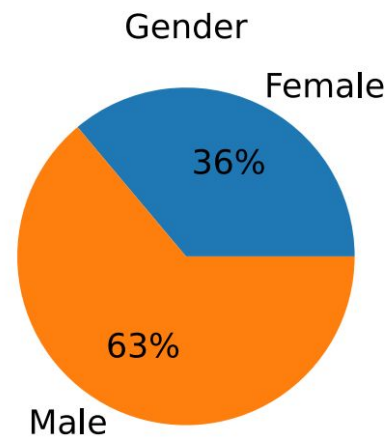
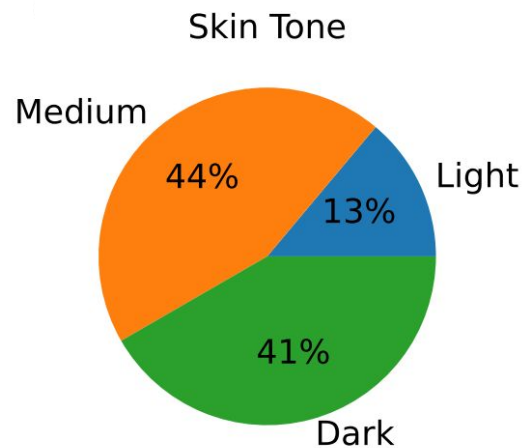


Pressure-Vision Net

- classification with 9 pressure levels
- encoder-decoder architecture with skip connections
- SEResNeXt50 encoder pre-trained on ImageNet
- feature pyramid network (FPN) decoder
- runs at 53 frames per second using an RTX 3090 GPU



36 participants, 64 hours of video

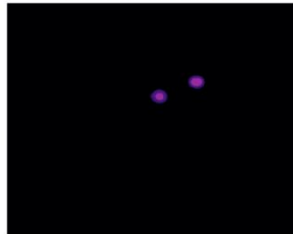




Input Image

Estimated Pressure

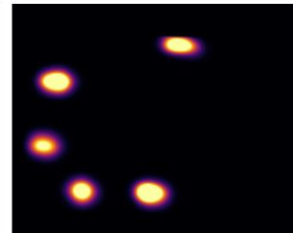
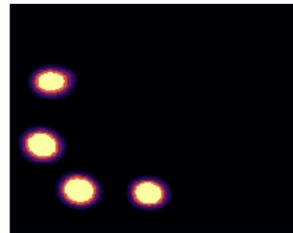
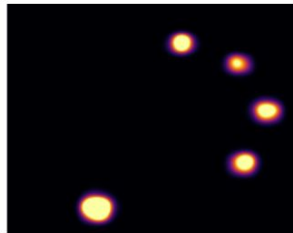
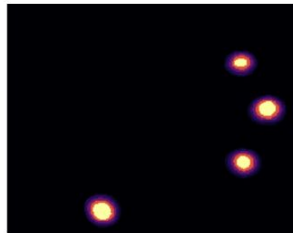
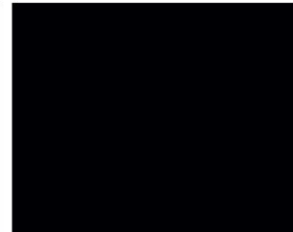
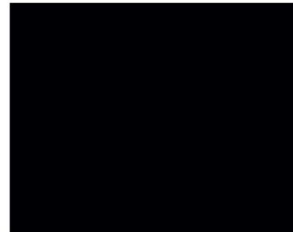
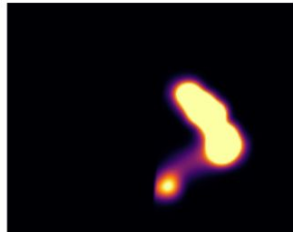
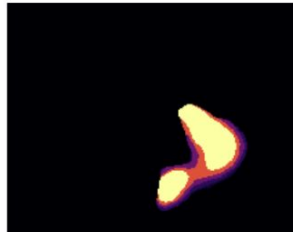
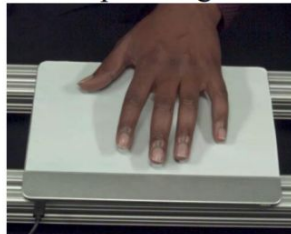
Ground Truth Pressure



Input Image

Estimated Pressure

Ground Truth Pressure



Input: RGB Image



Ground Truth Pressure

Estimated Pressure



Input: RGB Image



Ground Truth Pressure

Estimated Pressure

Input: RGB Image



Ground Truth Pressure

Estimated Pressure





Ground Truth Pressure

Estimated Pressure

Method	Temporal Acc	Contact IoU	Vol. IoU	MAE
Zero Guesser	53.7%	0.0%	0.0%	51.9 Pa
3D Pose Baseline [49]	78.1%	13.0%	-	-
PressureVisionNet	96.2%	55.8%	41.3%	39.9 Pa

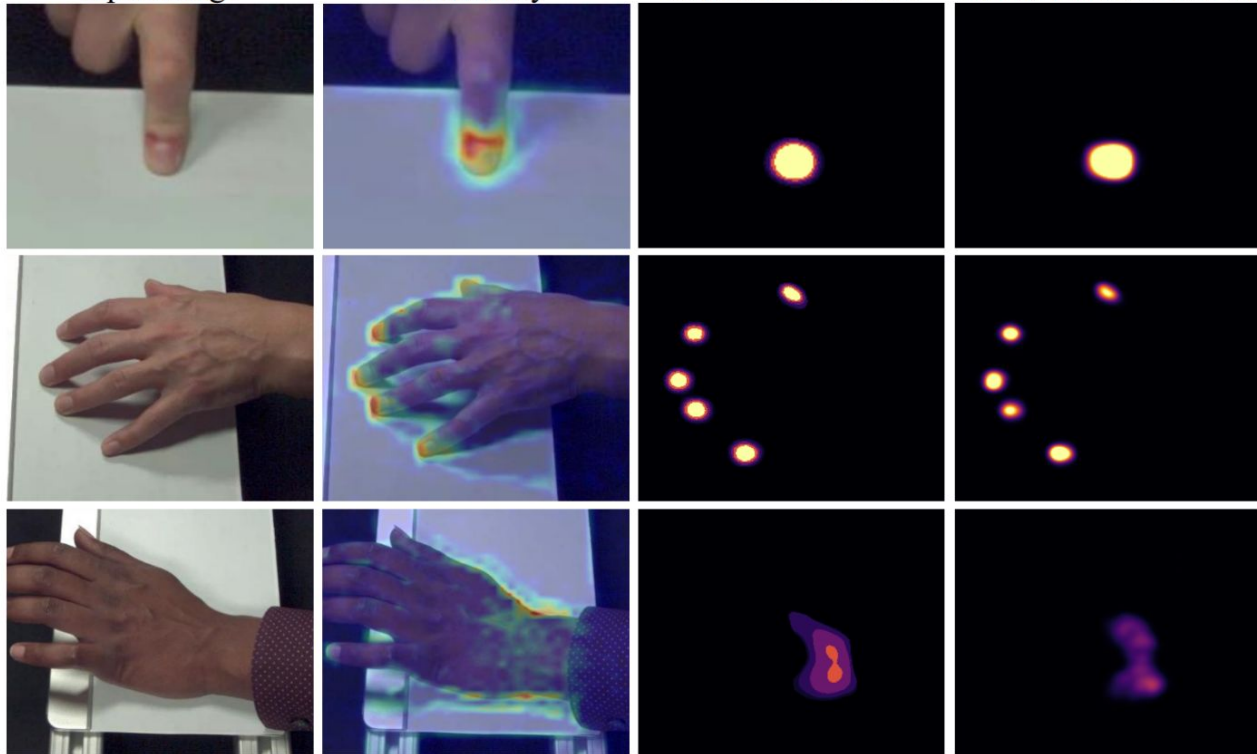
Sensitivity Images

Input Image

Sensitivity

Estimated Pressure

Ground Truth Pressure

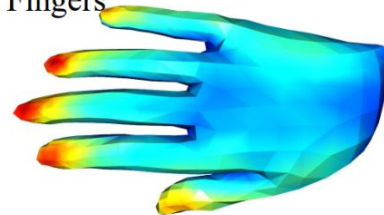


Projected Sensitivity

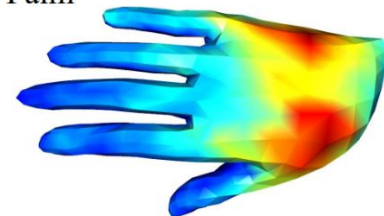
Press Index

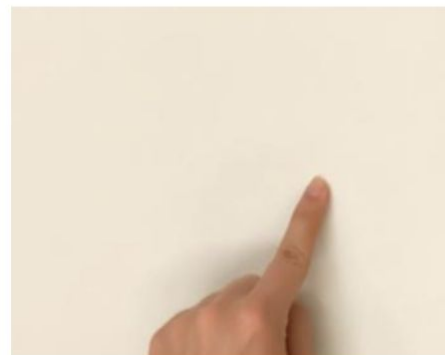
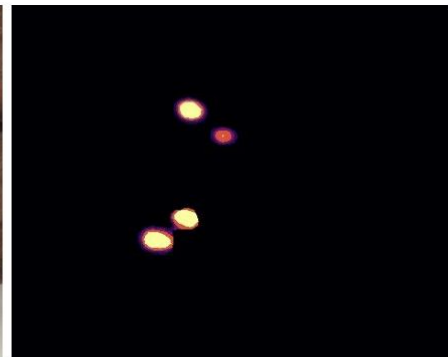
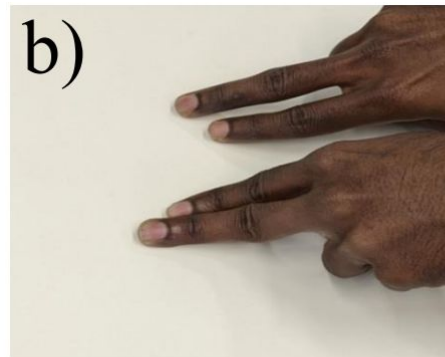


Press All Fingers



Press Palm





Input: RGB Image



Ground Truth Pressure

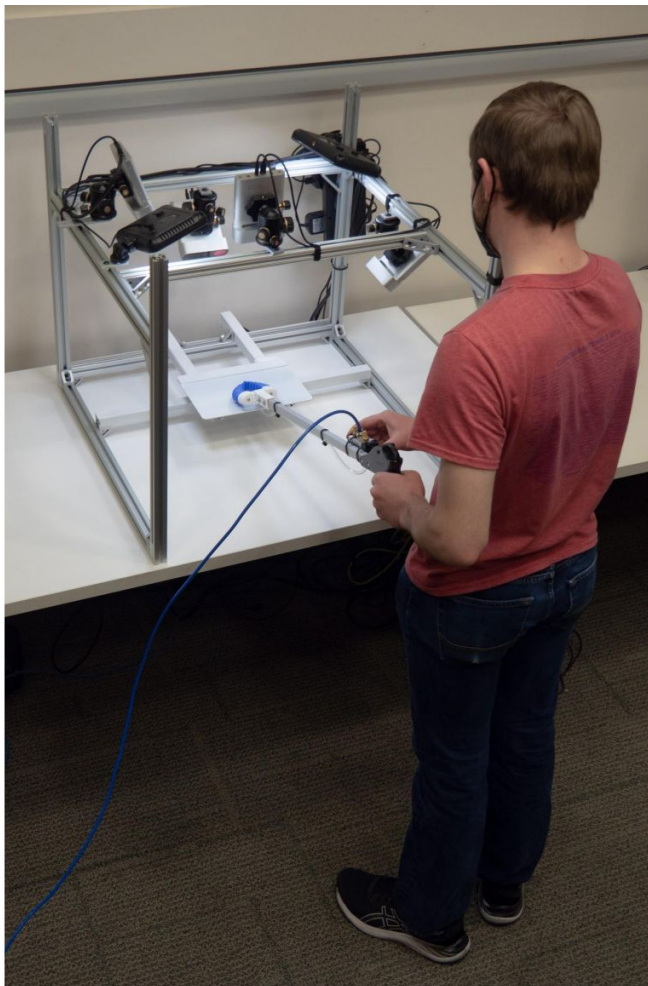
Estimated Pressure

Input: RGB Image



Ground Truth Pressure

Estimated Pressure



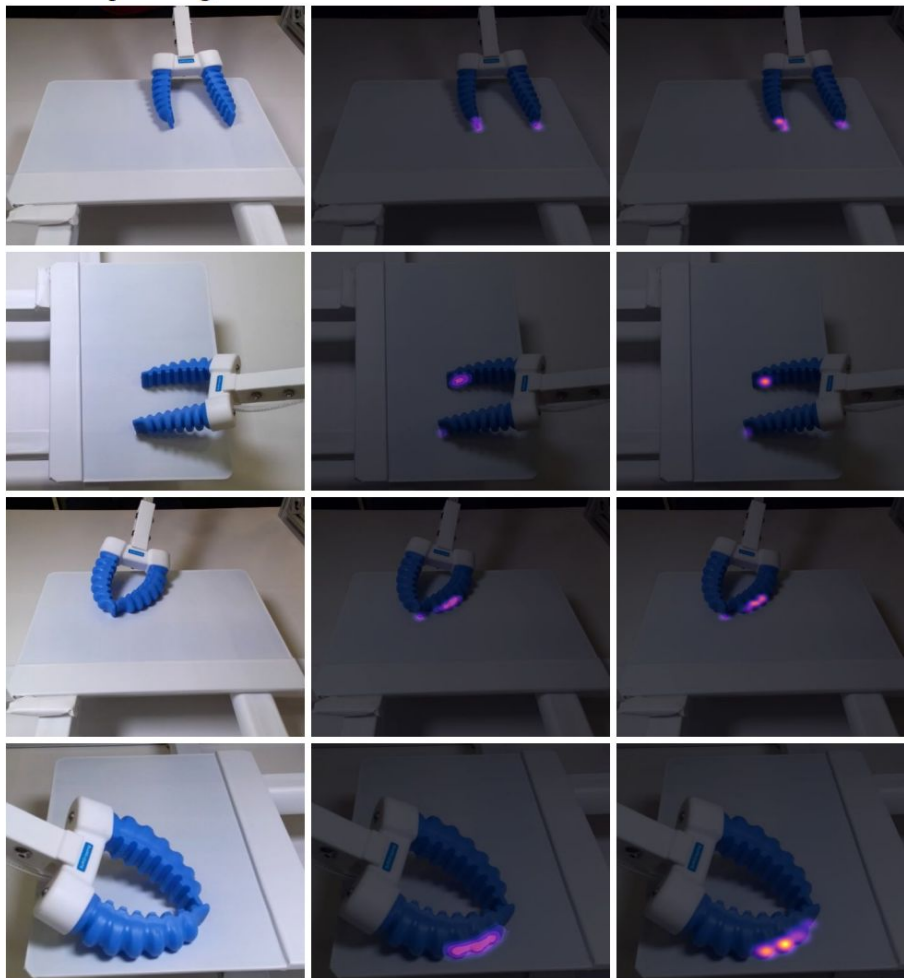
- Grippers manually operated
- ~1 hour of data for each gripper
- 650K frames total in the dataset

Dataset Collection

Input Image

Estimated Pressure

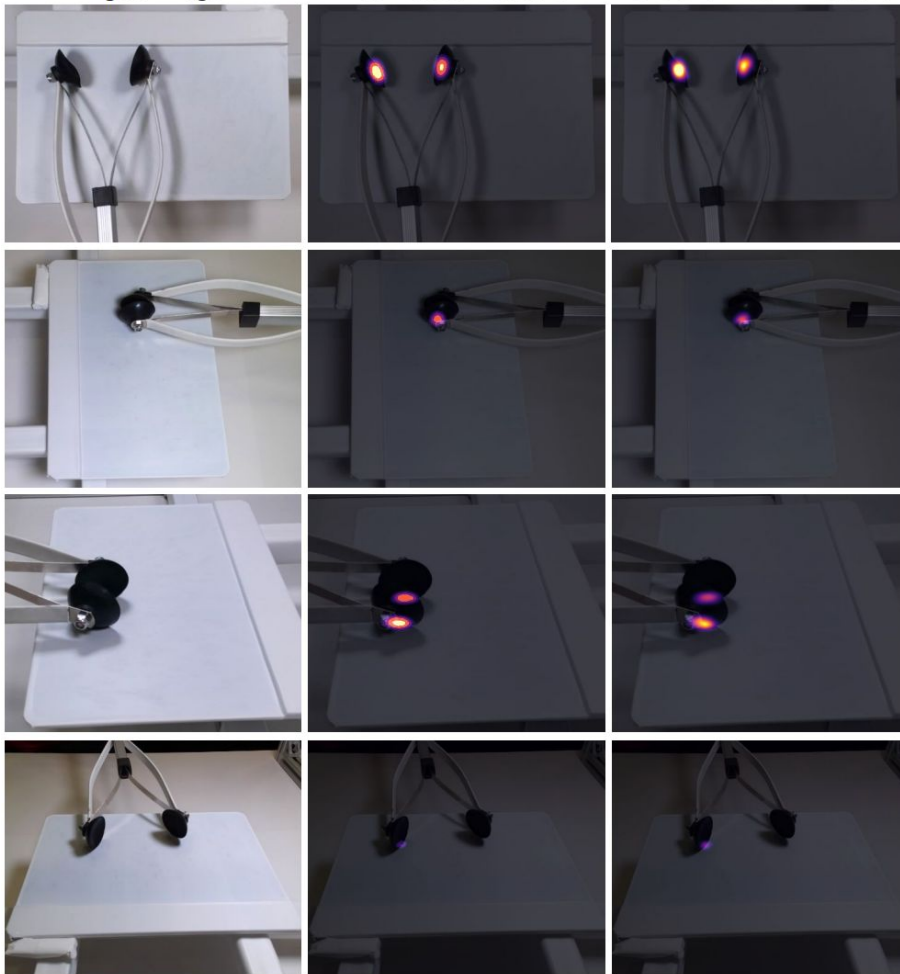
Ground Truth Pressure



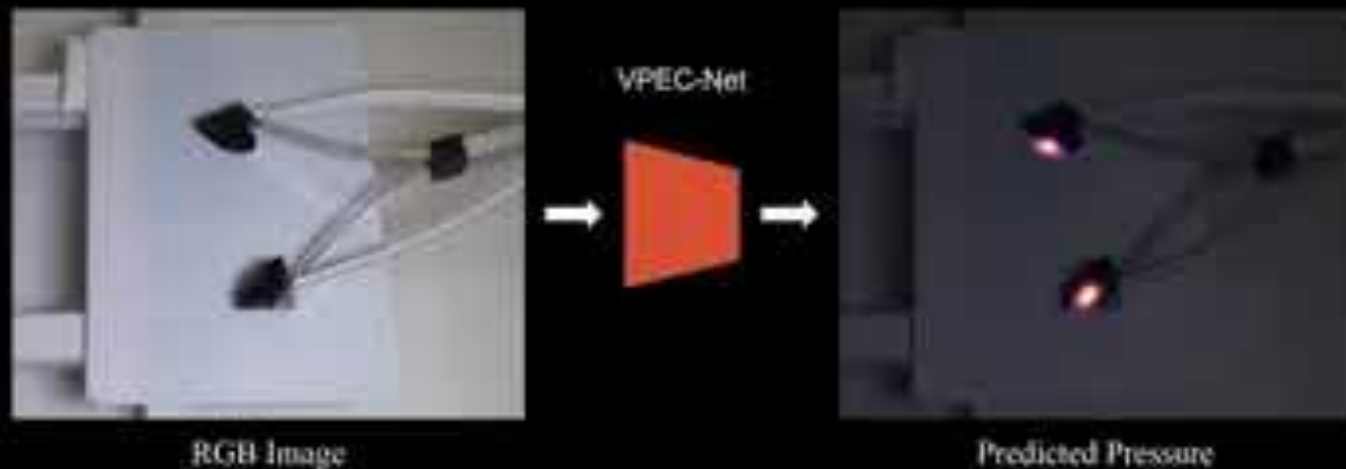
Input Image

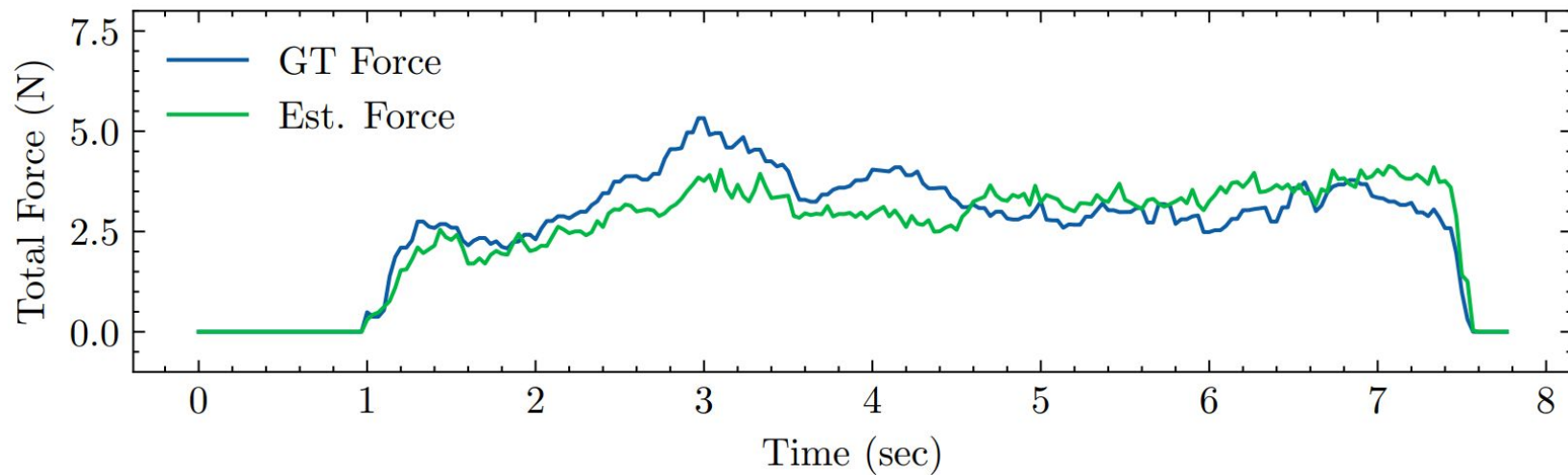
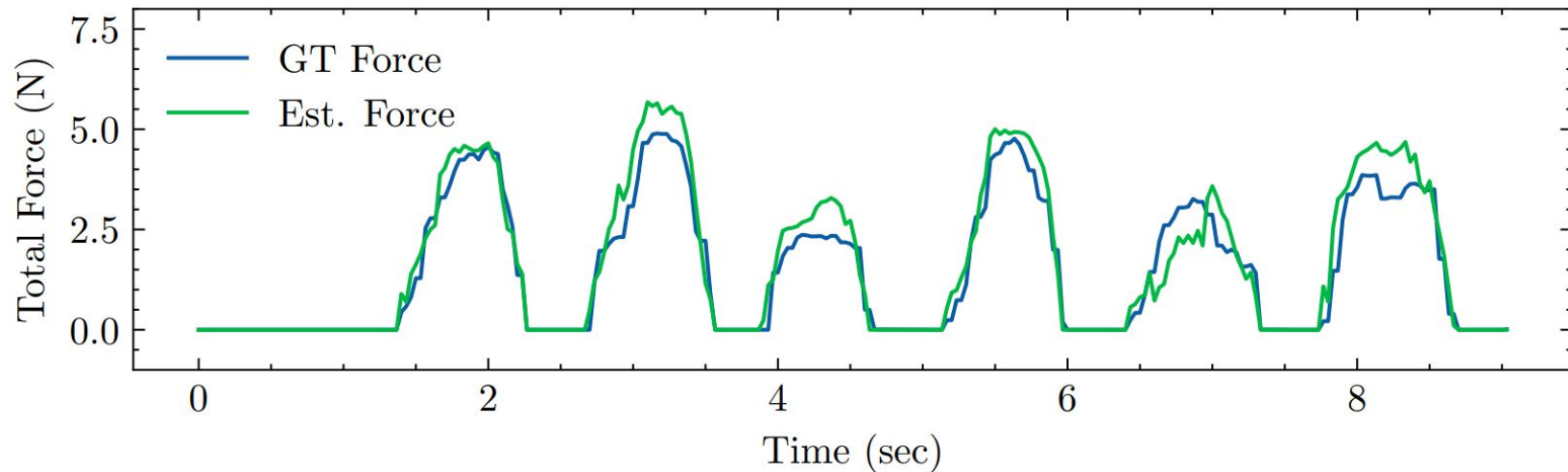
Estimated Pressure

Ground Truth Pressure



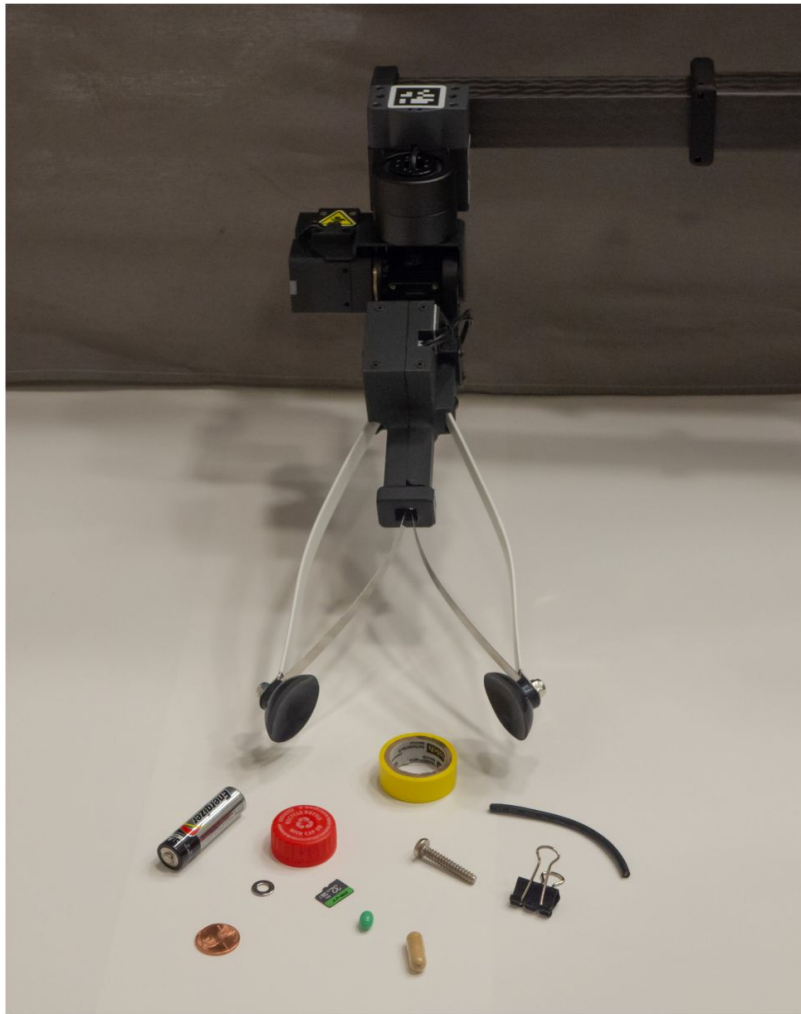
Visual Pressure Estimation and Control (VPEC)



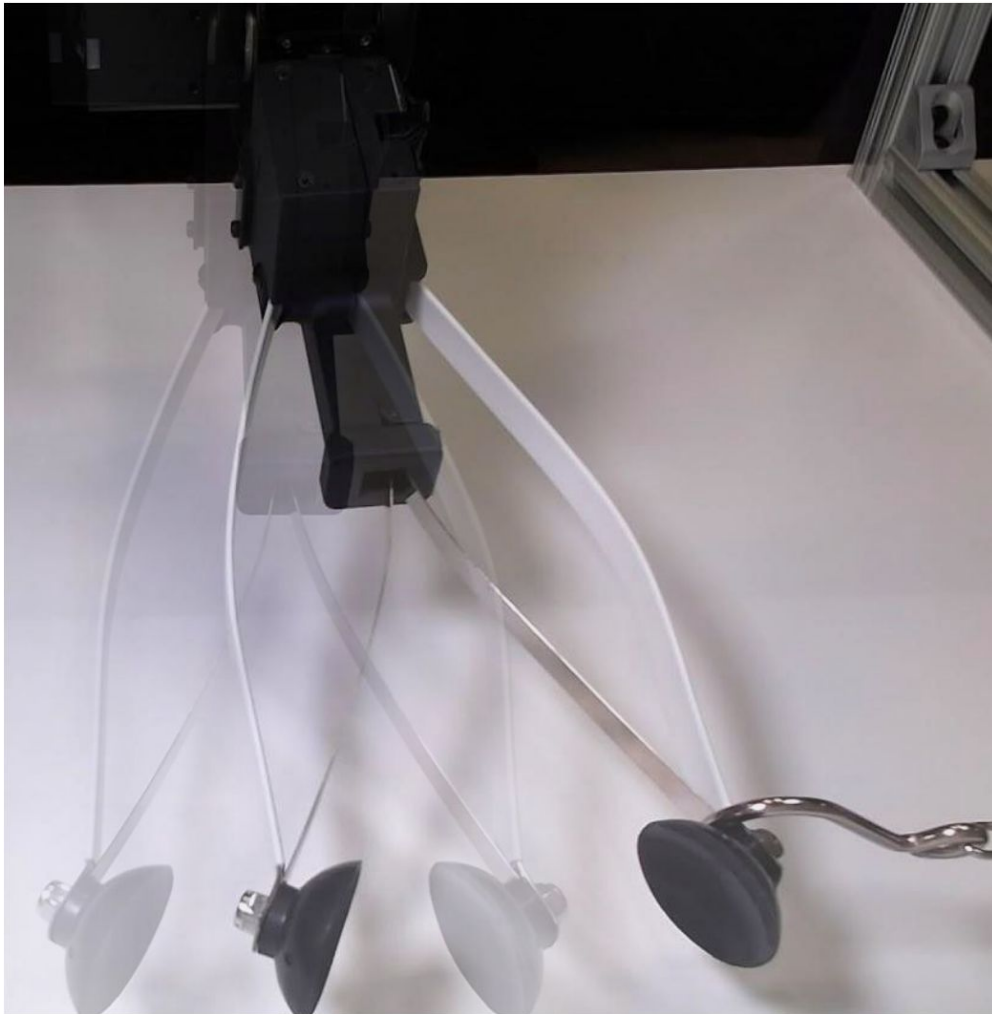


Method	Temporal Acc.	Contact IoU	Volumetric IoU	MAE
Tendon-Actuated Gripper	95.9%	73.8%	58.2%	5.3 Pa
Pneumatic Gripper	95.1%	63.3%	52.0%	9.7 Pa

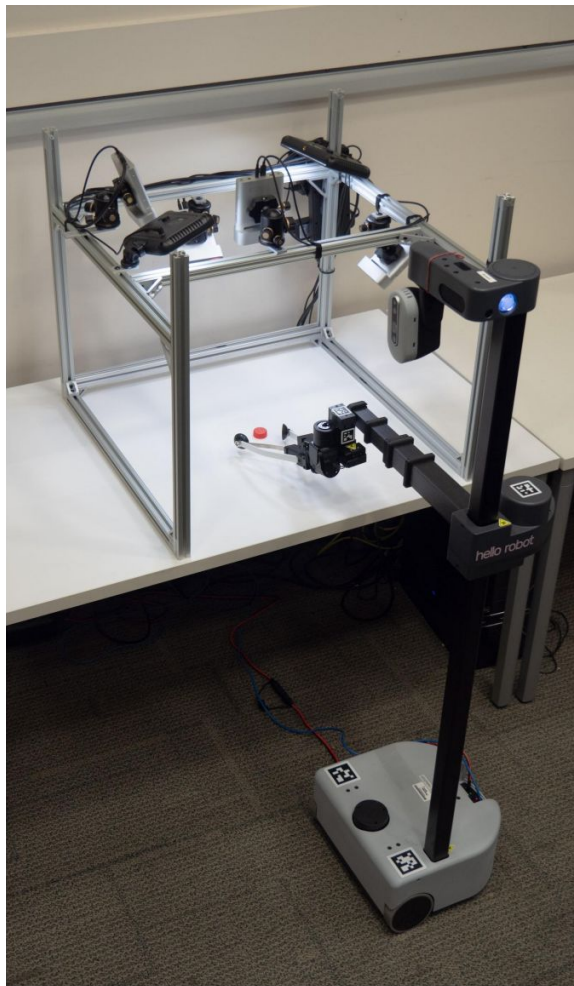
TABLE I
RESULTS OF VISUAL PRESSURE ESTIMATION



Object	Dims. L×W×H
Washer	10×10×1 mm
Small Green Pill	10×6×6 mm
Large Pill	21×8×8 mm
MicroSD Card	15×11×1 mm
Cable Segment	82×4×4 mm
Penny	19×19×1.5 mm
Bottle Cap	30×30×13 mm
AA Battery	50×14×14 mm
Binder Clip	25×24×19 mm
Screw	32×9×9 mm
Tape Roll	36×36×13 mm

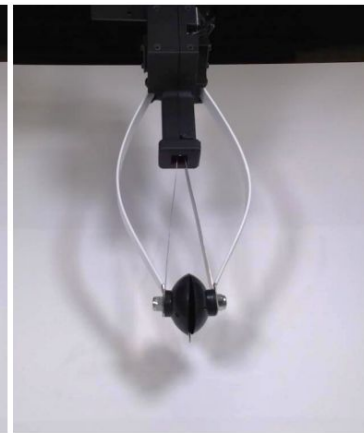
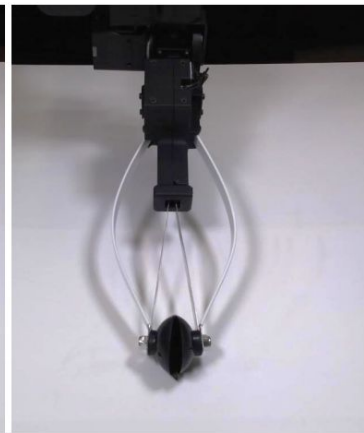
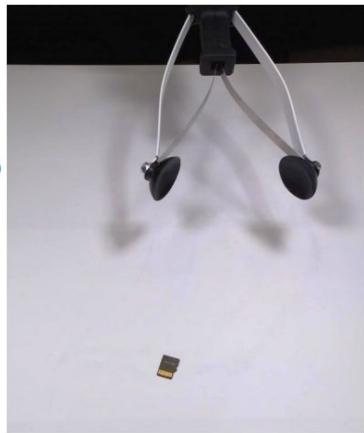


- 5N applied
- 4cm deflection

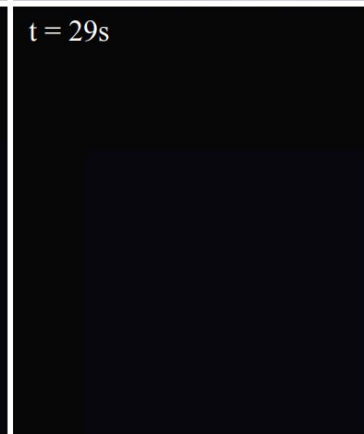
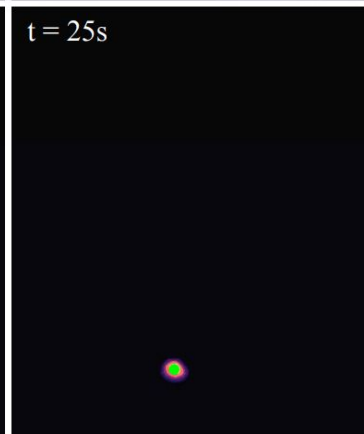
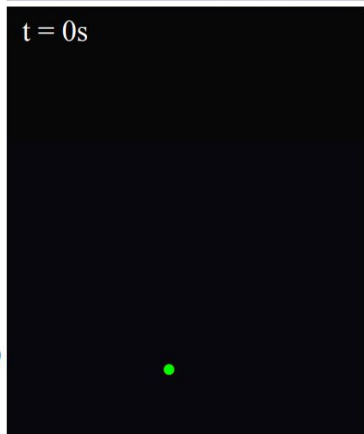


Robotic Manipulation

RGB Image



Target and Estimated Pressure



Initial Pose

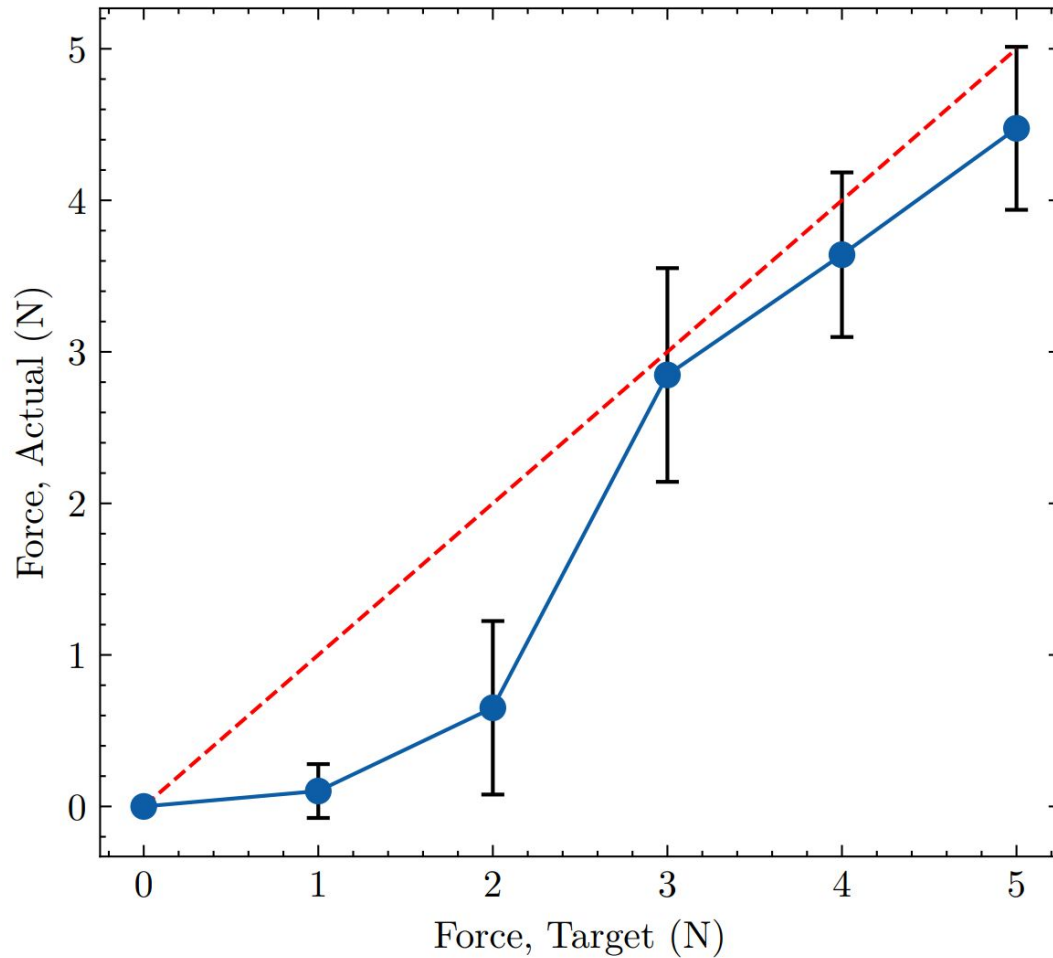
Make Contact

Approach Object

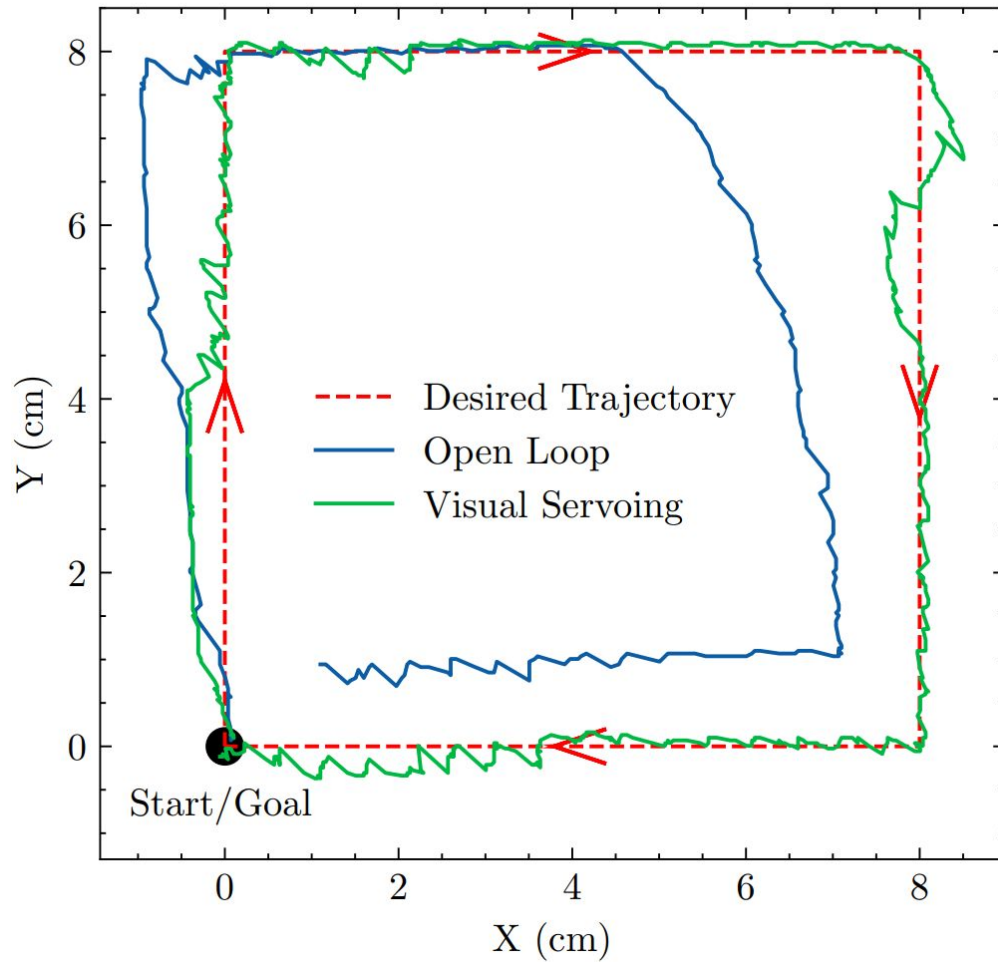
Grasp

Lift

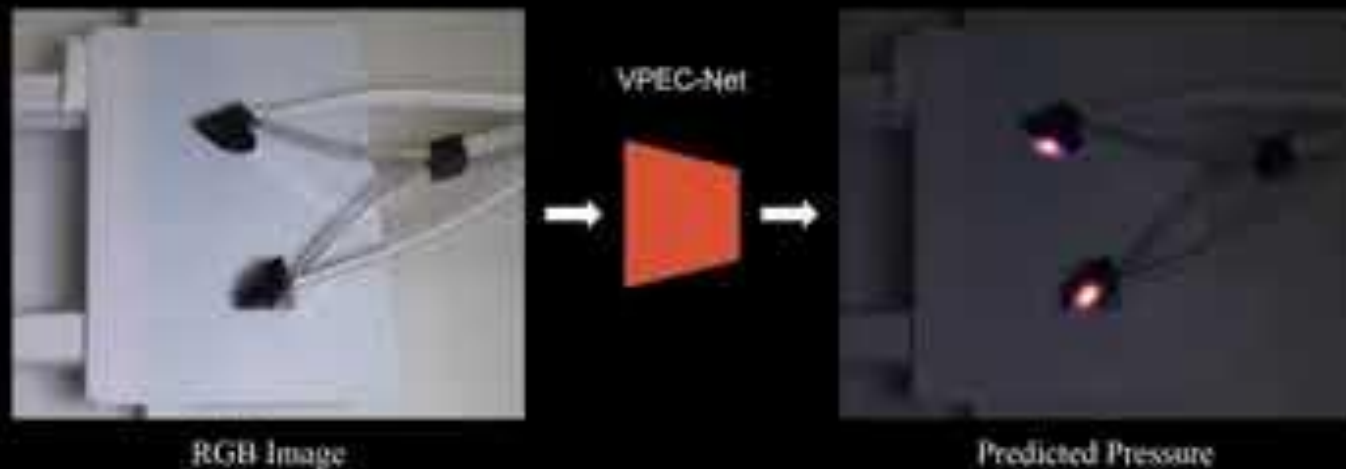
Accuracy of Closed-Loop Force Control

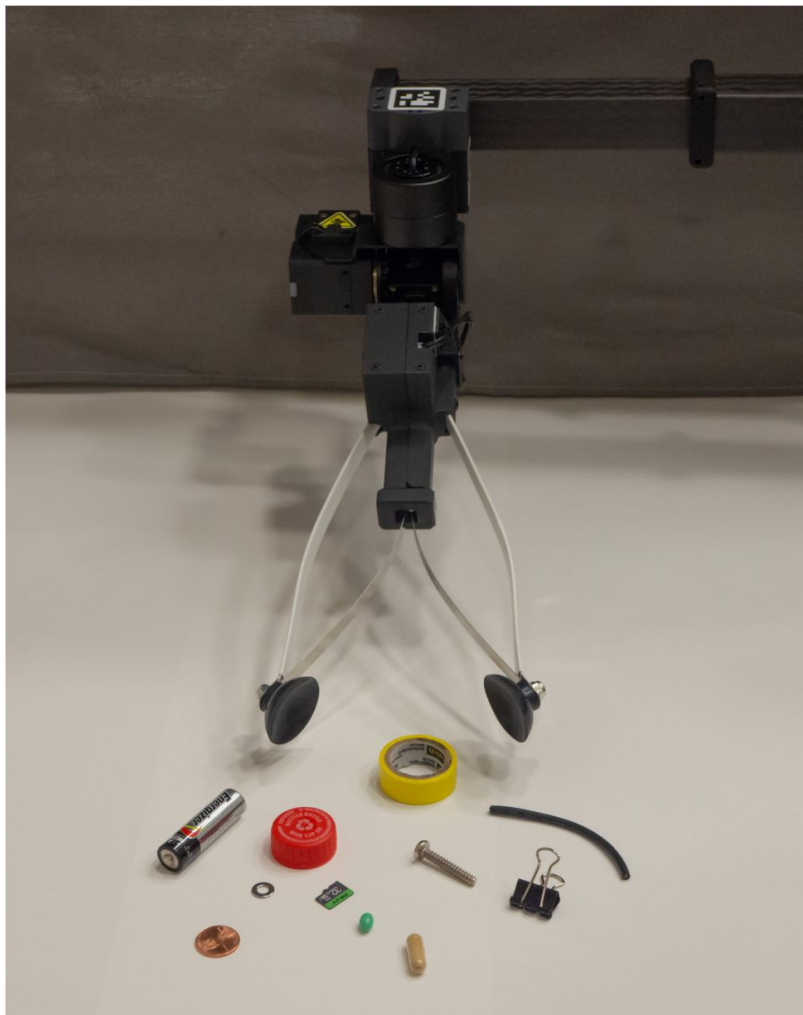


Robot Trajectory while in Contact



Visual Pressure Estimation and Control (VPEC)

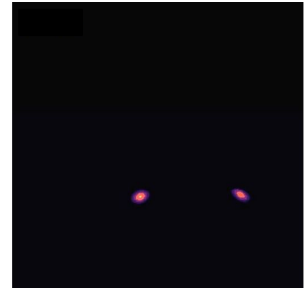




Object	Dims. L×W×H	Grasp Successes/Trials
Washer	10×10×1 mm	9/10
Small Green Pill	10×6×6 mm	10/10
Large Pill	21×8×8 mm	9/10
MicroSD Card	15×11×1 mm	8/10
Cable Segment	82×4×4 mm	10/10
Penny	19×19×1.5 mm	9/10
Bottle Cap	30×30×13 mm	9/10
AA Battery	50×14×14 mm	9/10
Binder Clip	25×24×19 mm	9/10
Screw	32×9×9 mm	10/10
Tape Roll	36×36×13 mm	10/10

Key Points

- Vision can be used to estimate contact pressure
- Same method works for human hands and soft robotic grippers
- Trained models
 - Input: **RGB image**
 - Output: **aligned pressure image**
 - Performed well across human skin tones
 - Generalized to new human hands
 - Enabled precision manipulation via visual servoing



PressureVision: Estimating Hand Pressure from a Single RGB Image, Patrick Grady, Chengcheng Tang, Samarth Brahmhatt, Christopher D. Twigg, Chengde Wan, James Hays, Charles C. Kemp, European Conference on Computer Vision (ECCV), 2022.

Visual Pressure Estimation and Control for Soft Robotic Grippers, Patrick Grady, Jeremy A. Collins, Samarth Brahmhatt, Christopher D. Twigg, Chengcheng Tang, James Hays, Charles C. Kemp, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2022.