Vision and Touch: Multimodal or Cross-modal?

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An overview

1. Synesthesia: Touching to See and Seeing to Feel
2. Senses of Robots: Sensors
3. Object representations using tactile images
4. Integrated visual-tactile perception
5. Interactive Perception

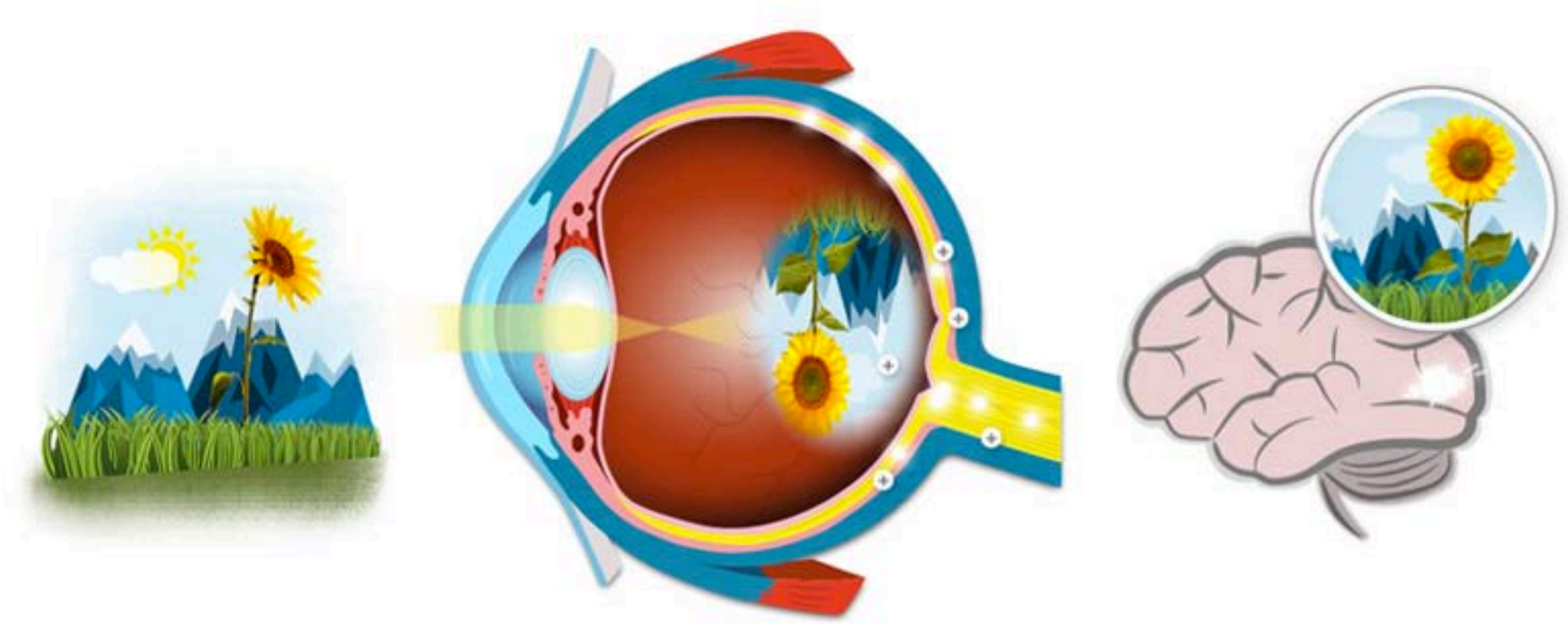
Biological synesthesia

Human vs Robot perception

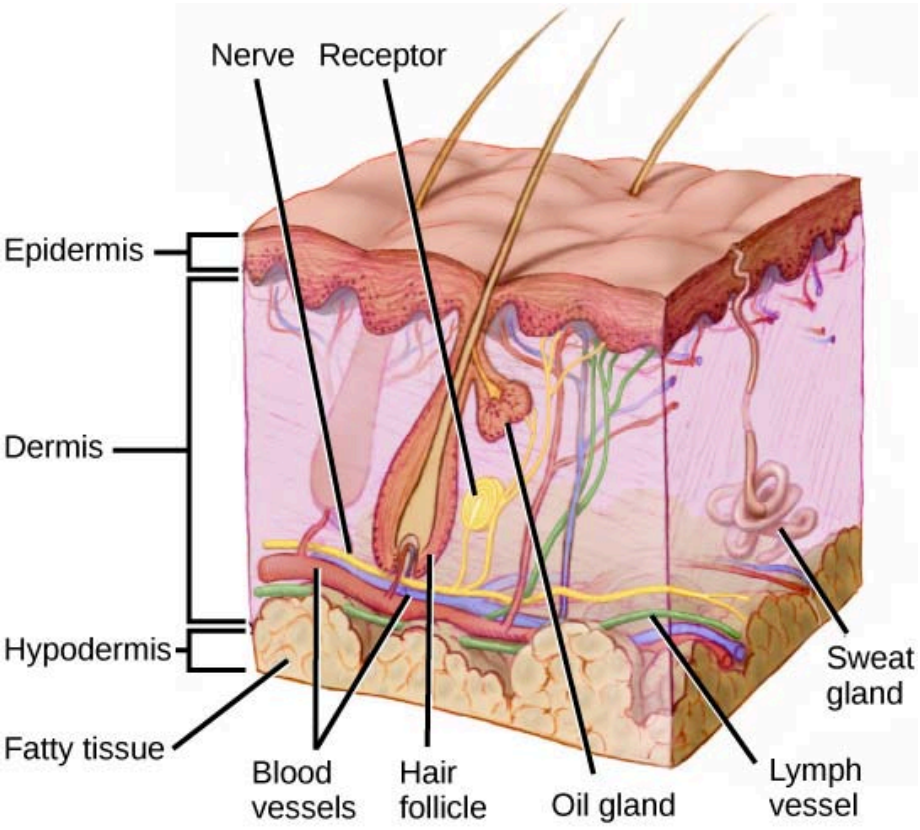
Vision
Tactile sensing
Proprioception
Auditory sensing
Representation
Action
Interaction
Communication
…

PR2: www.willowgarage.com/pages/pr2

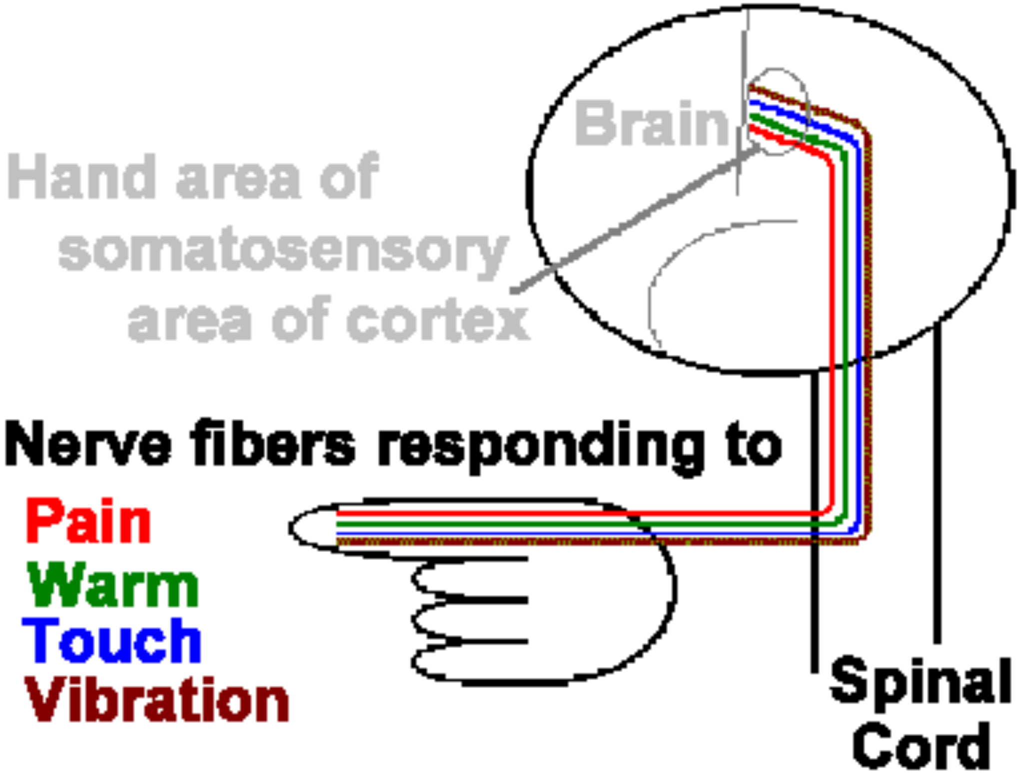
Human vision



Human touch

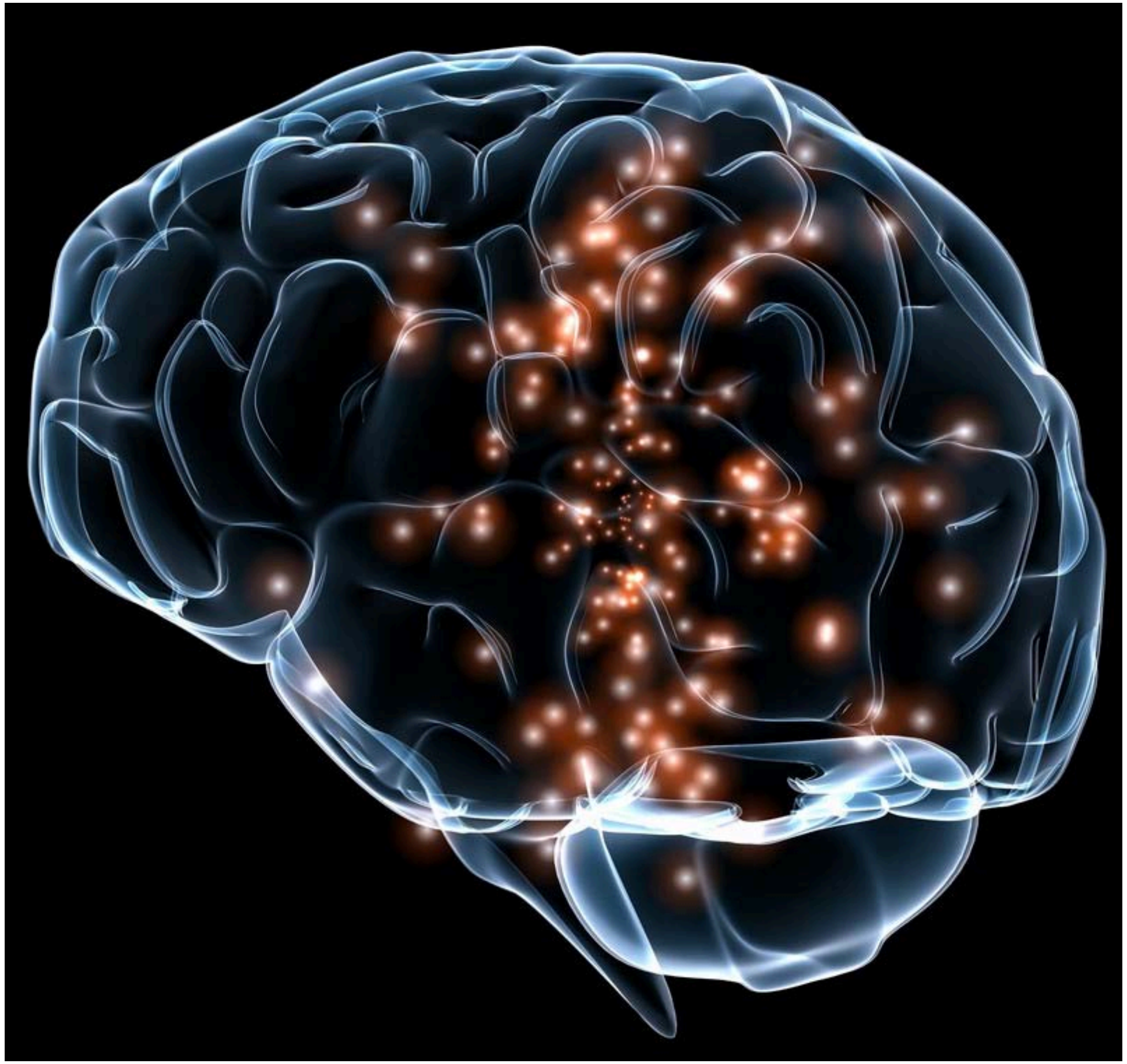


Nerve
Receptor
Epidermis
Dermis
Hypodermis
Fatty tissue
Blood vessels
Hair follicle
Oil gland
Lymph vessel
Sweat gland

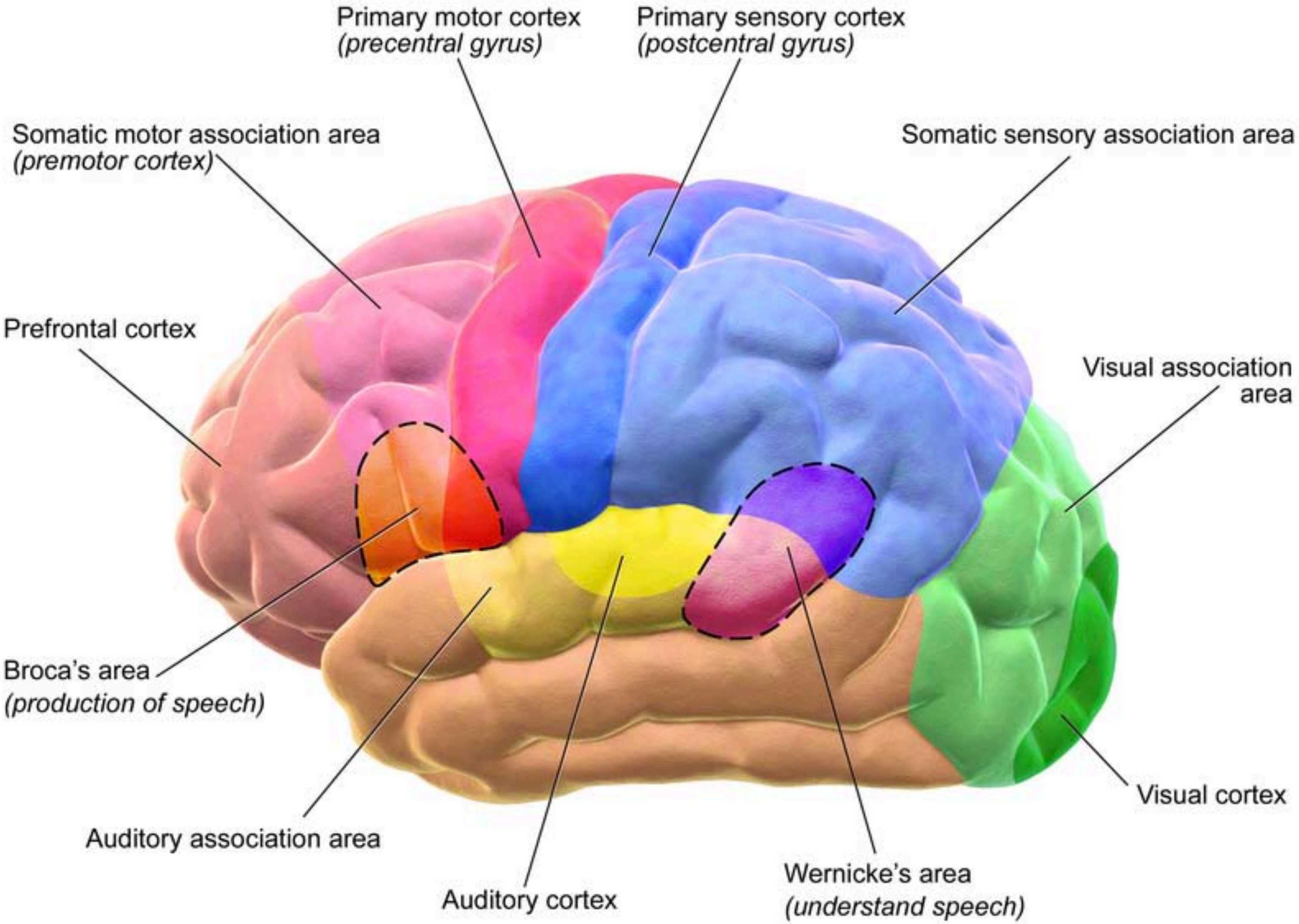


Brain
Hand area of somatosensory area of cortex
Nerve fibers responding to
Pain
Warm
Touch
Vibration
Spinal Cord

Human multimodal sensation



Human multimodal sensation



Macaluso, E. and Driver, J., 2001. Spatial attention and crossmodal interactions between vision and touch. *Neuropsychologia*, *39*(12), pp.1304-1316.

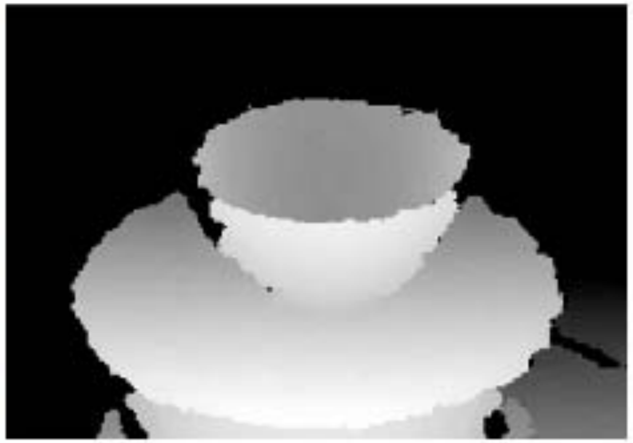
Senses of Robot: Sensors

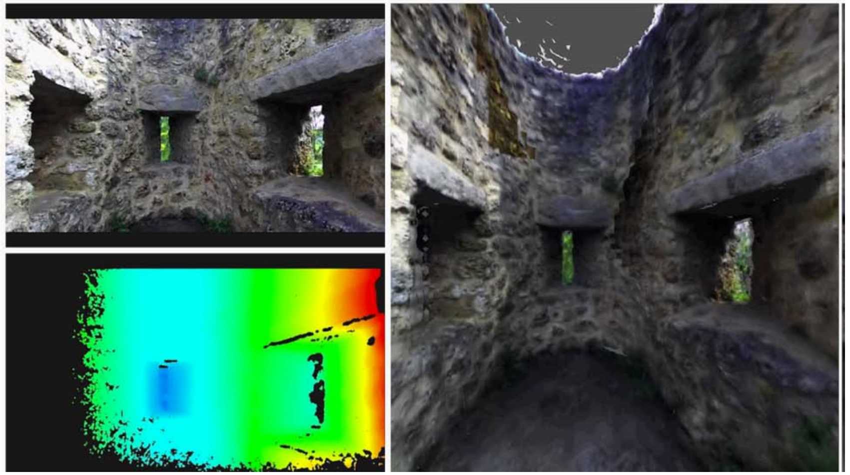
Eyes – Cameras

Webcams

Depth sensor

Stereo camera



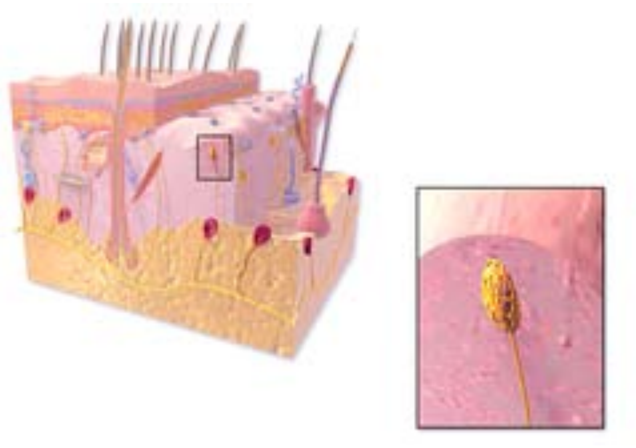


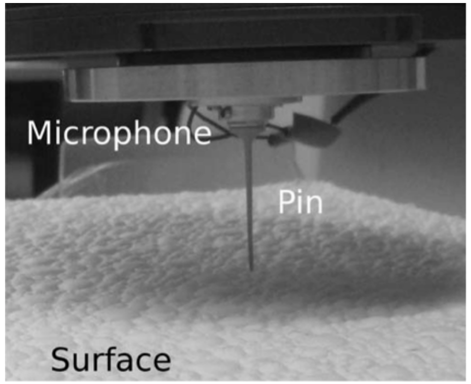
RGB-D Object Dataset

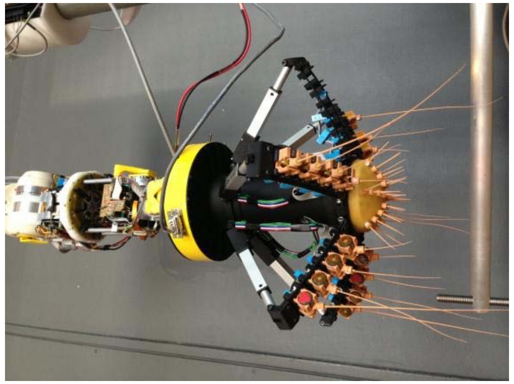
Touch – Tactile sensors

Type	Advantages	Disadvantages	Examples
Capacitive	Taxels can be very small; High spatial resolution; Sensitive to small forces; High frequency response.	Hysteresis; Sensitive to electro-magnetic noise and temperature change; Non-linear response; Cross-talk; Complex electronics.	PPS DigiTacts
Piezoelectric	Good workability; Flexibility; Chemical stability; Fast dynamic response.	Sensitive to temperature; Fragility of electrical junctions; Dynamic measurements only.	PVDF
Optical	Magnetic resonance compatible; Flexible and fast; No interconnections	Bulky sizes; High power consuming.	Optical fibres
Piezo-resistive	Economic; Sensitive and robust; Easy to manufacture.	High power consuming; Low repeatability; Fragile to shear forces.	Weiss tactile sensors
Tunnel effect	High spatial resolution; High dynamic range.	Bulky sizes; Non-linear response.	QTC touch sensors
Ultrasonic-based	Fast dynamic response; Good force resolution.	Bulky sizes; limited utility at low frequency; sensitive to temperature.	
Magnetism-based	Sensitive and robust; No measurement hysteresis.	Limited to nonmagnetic mediums.	MagOne
Barometer-based	Good elasticity; Low cost.	Low spatial resolution.	TakkTile; BioTac
Camera-based	Extra high spatial resolution.	Bulky sizes.	GelSight
Graphene	Flexible, extra thin	Still too high price	Dahiya ‘17

Tactile sensors - Single-contact (haptic) sensors

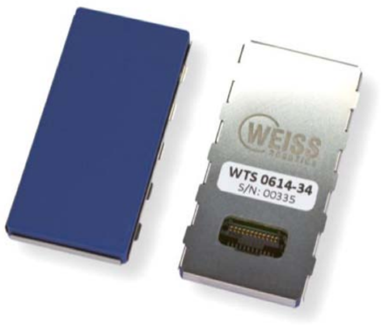






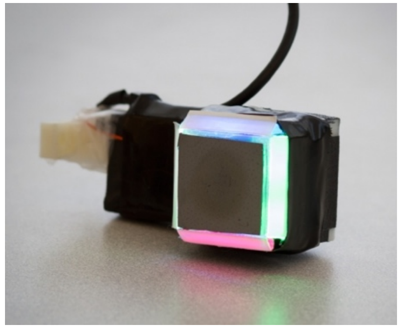
Kroemer, *et al.* "Learning dynamic tactile sensing with robust vision-based training." *T-RO*, 2011.
Lepora. "Biomimetic Active Touch with Tactile Fingertips and Whiskers." *IEEE Trans. Haptics*, 2016.

Tactile sensors - High spatial resolution sensors



Weiss Robotics

Pressure Profile Systems (PPS)



GelSight

Multimodal BioTac

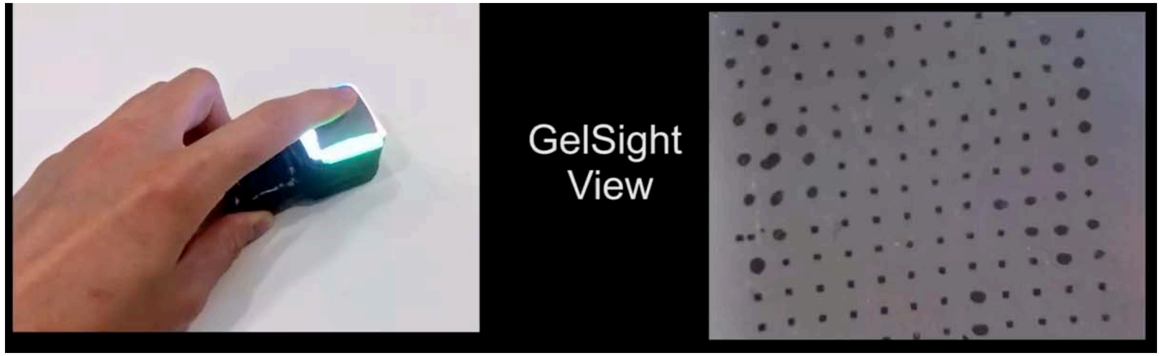
Tekscan

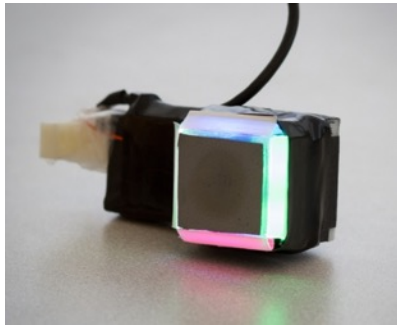
Human finger

Density of Merkel receptors in the fingertip: around 14×14

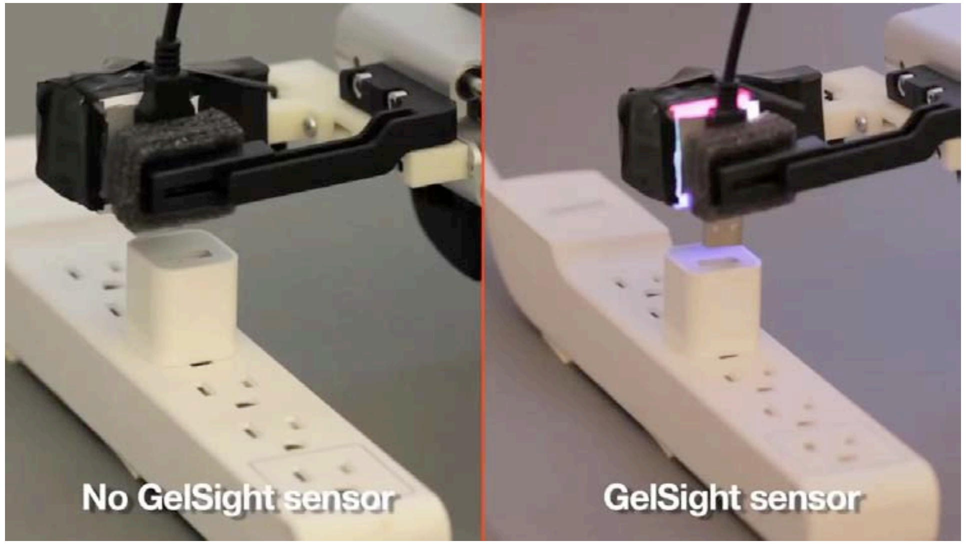
Pezzementi, *et al.* "Tactile-object recognition from appearance information." T-RO, 2011.

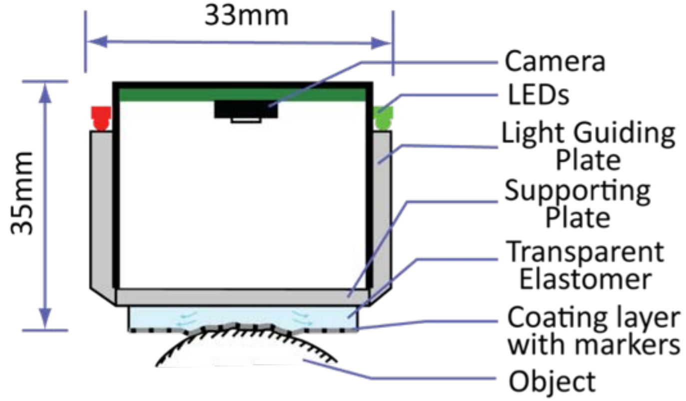
Tactile sensors - High spatial resolution sensors





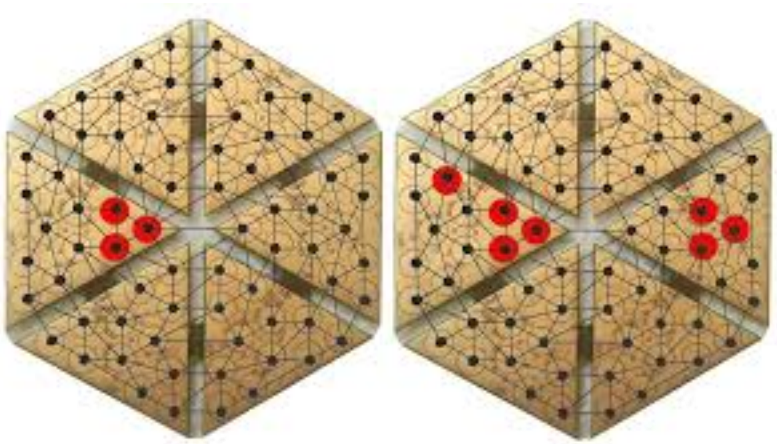
GelSight sensor

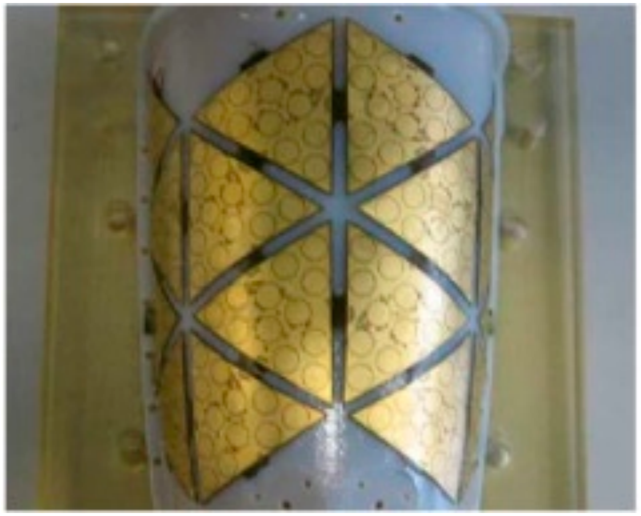




Shan Luo, *et al.*, "Robotic Tactile Perception of Object Properties: A Review" *Mechatronics*, 2017.

Tactile sensors - Large-area tactile sensors





Kaltenbrunner, *et al*. “An ultra-lightweight design for imperceptible plastic electronics.” Nature, 2013.
Schmitz, *et al.* “Methods and technologies for the implementation of large-scale robot tactile sensors.” T-RO, 2011.
P. Mittendorfer, and G. Cheng,. Humanoid multimodal tactile-sensing modules. T-RO, 2011.

Touch – Tactile sensors

Modality	FoV	Info.	Compl.	Compu.	Invariance
Visual	Global	Rich	Low	High	Scaling, rotation, translation, illumination
Tactile	Local	Sparse	High	Low	Rotation, translation, "illumination"

Shan Luo, *et al.*, "Robotic Tactile Perception of Object Properties: A Review" *Mechatronics*, 2017.

Object representations using tactile images

Object representations in the robot world

Local shape
Global shape
Locations
Texture
Pose
…

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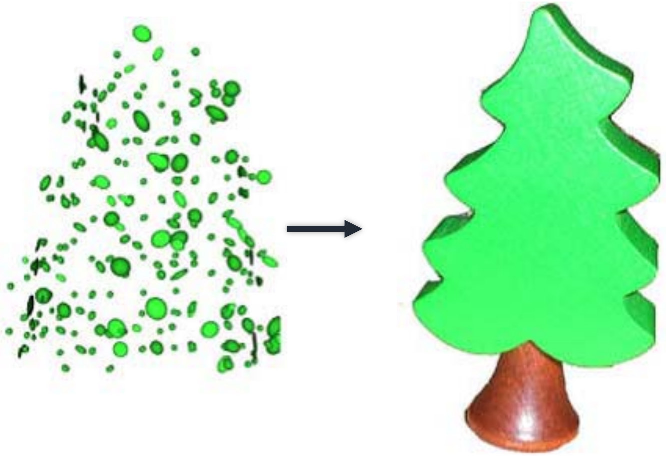
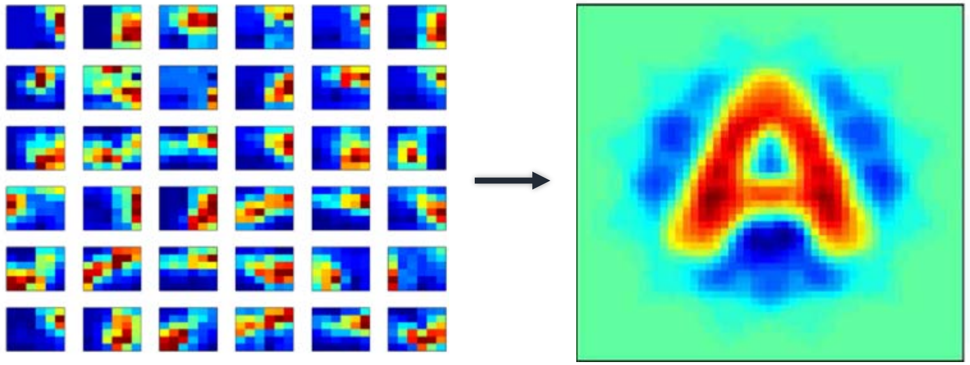
Global shape recognition

Contact points based recognition





Tactile sensor readings

Tactile point clouds

Occupancy grid mapping

Pro: Arbitrary contact shapes can be retrieved.

Con: Time consuming when investigating a large object surface.

M. Meier*, et al*., "A Probabilistic Approach to Tactile Shape Reconstruction " *IEEE Trans. Robot*., 2011.

Z. Pezzementi, *et al.,* "Object mapping, recognition, and localization from tactile geometry," *ICRA*, 2011.

Global shape recognition

Tactile patterns based recognition

Feature
Extraction

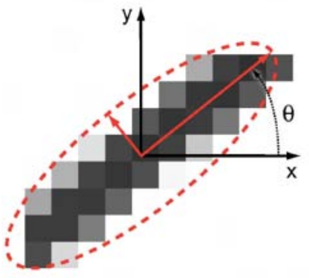
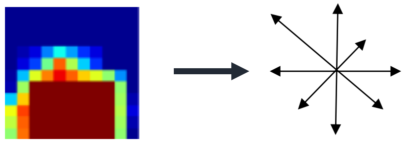
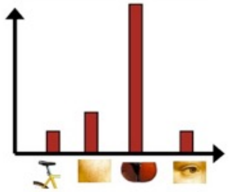


Image moments



Tactile-SIFT

Bag-of-Words
Framework

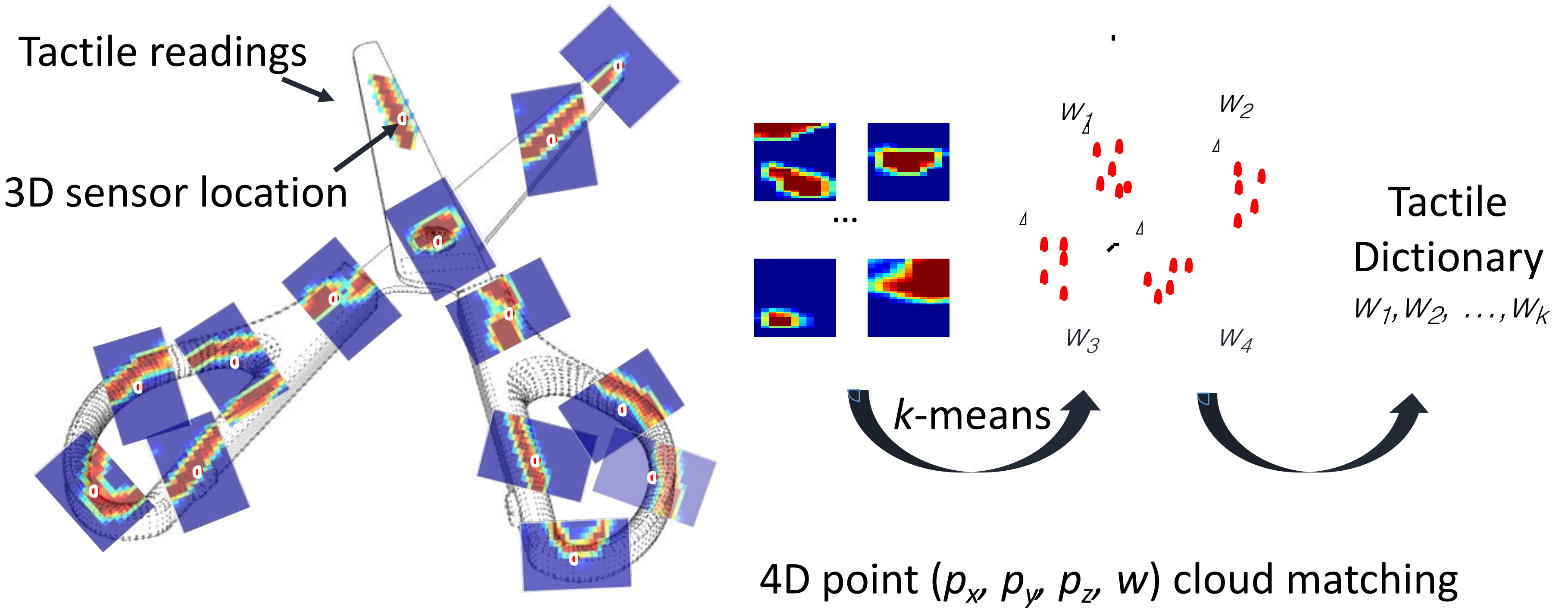


Pro: Local features can be revealed.
Con: Three-dimensional distribution information is not incorporated.

Z. Pezzementi, *et al.*, “Tactile-Object Recognition From Appearance Information,” *IEEE Trans. Robot.*, 2011.
S. Luo, *et al.*, “Novel Tactile-SIFT Descriptor for Object Shape Recognition”, *IEEE Sensors J.*, 2015.

Global shape recognition

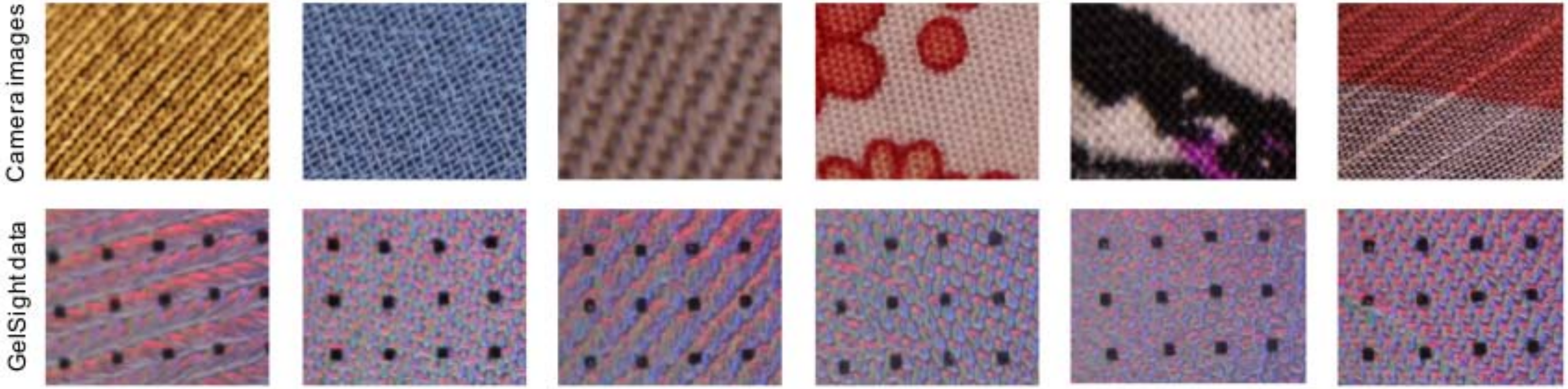
Shape representation in 4D space



Shan Luo, *et al.*, “iCLAP: Shape Recognition by Combining Proprioception and Touch Sensing.”, *Autonomous Robots*, 2018
Shan Luo, *et al.*, “Iterative Closest Labeled Point for Tactile Object Shape Recognition.” IROS, 2016.

Integrated visual-tactile perception

Feature sharing between vision and tactile sensing



Gelsight tactile sensor

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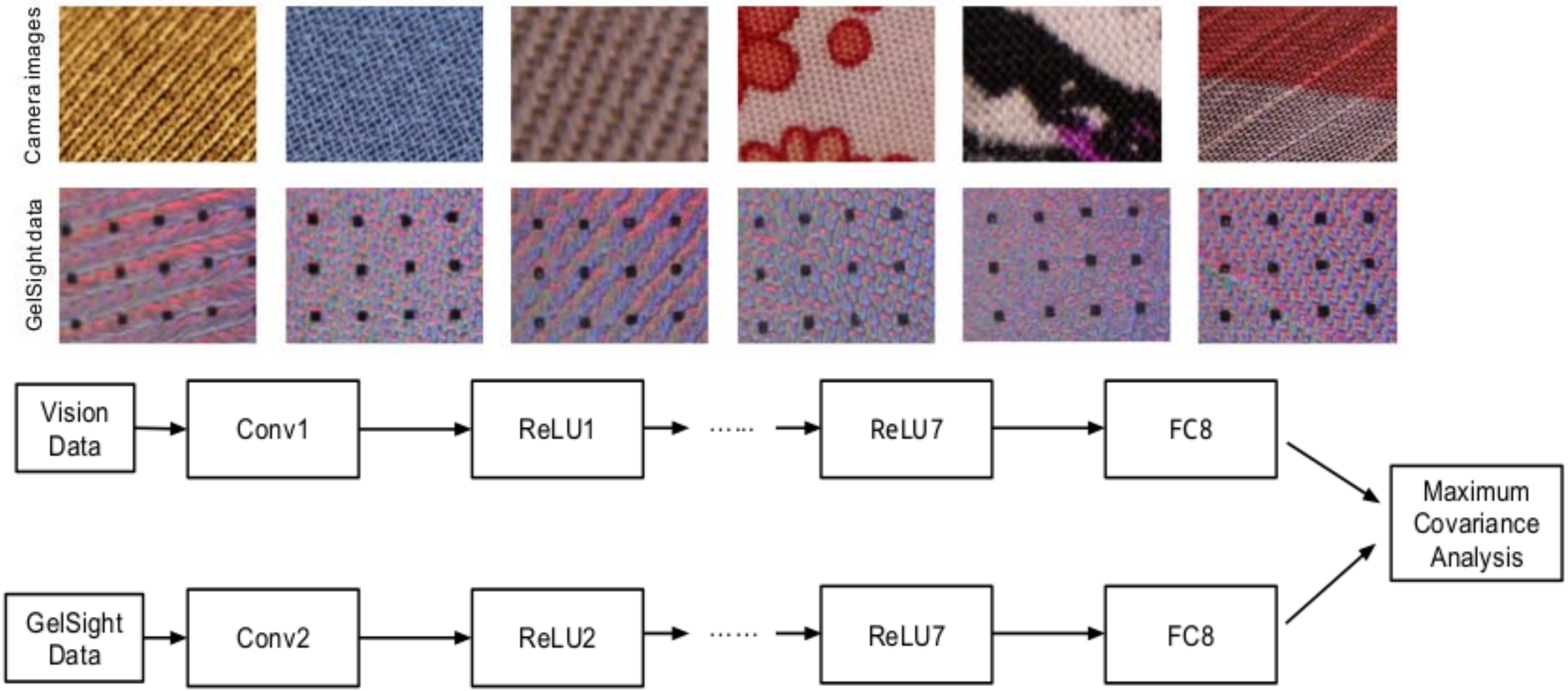
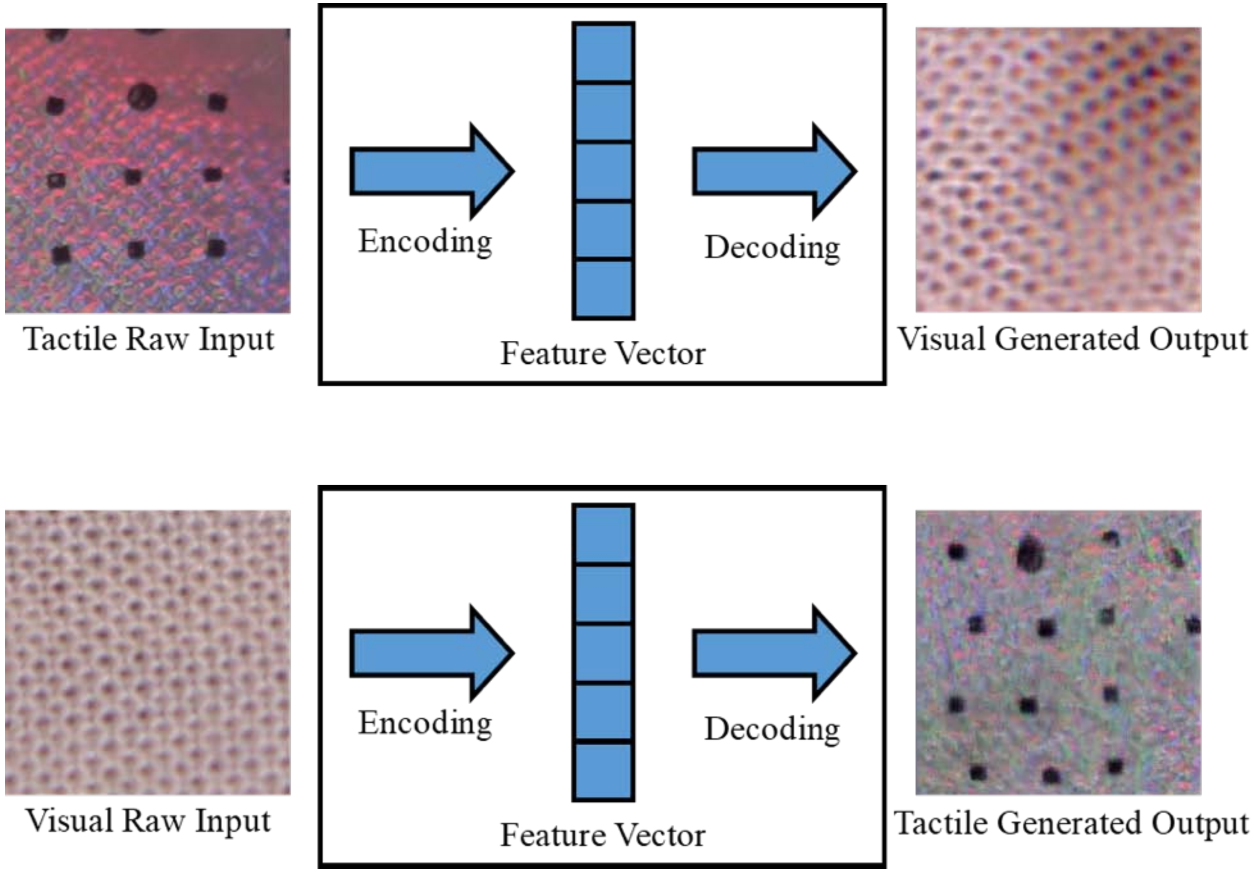
Shan Luo, *et al.*, “ViTac: Feature Sharing between Vision and Tactile Sensing for Cloth Texture Recognition”, *ICRA*, 2018.

Feature sharing between vision and tactile sensing



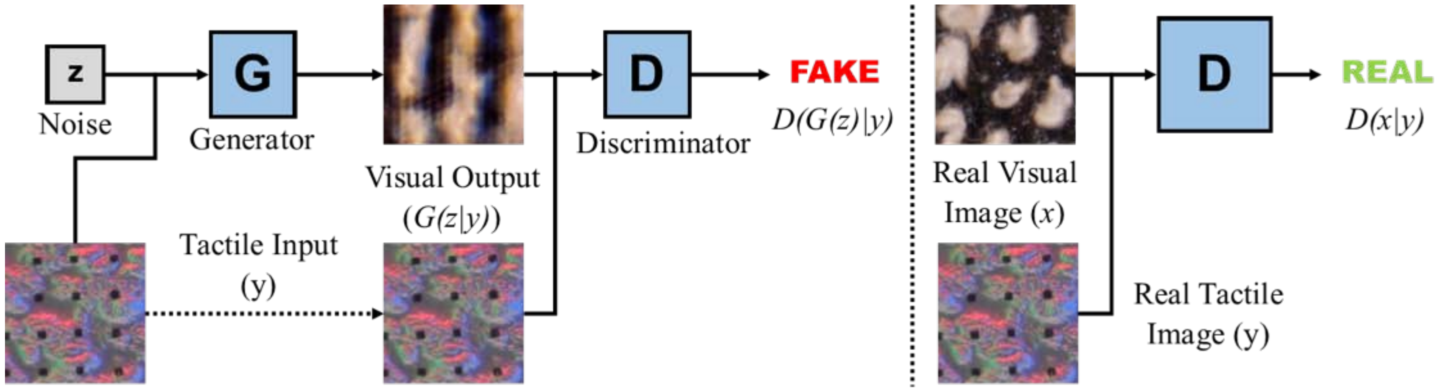
Shan Luo, *et al.*, “ViTac: Feature Sharing between Vision and Tactile Sensing for Cloth Texture Recognition”, *ICRA*, 2018.

“Touch to See” and “Seeing to Feel”

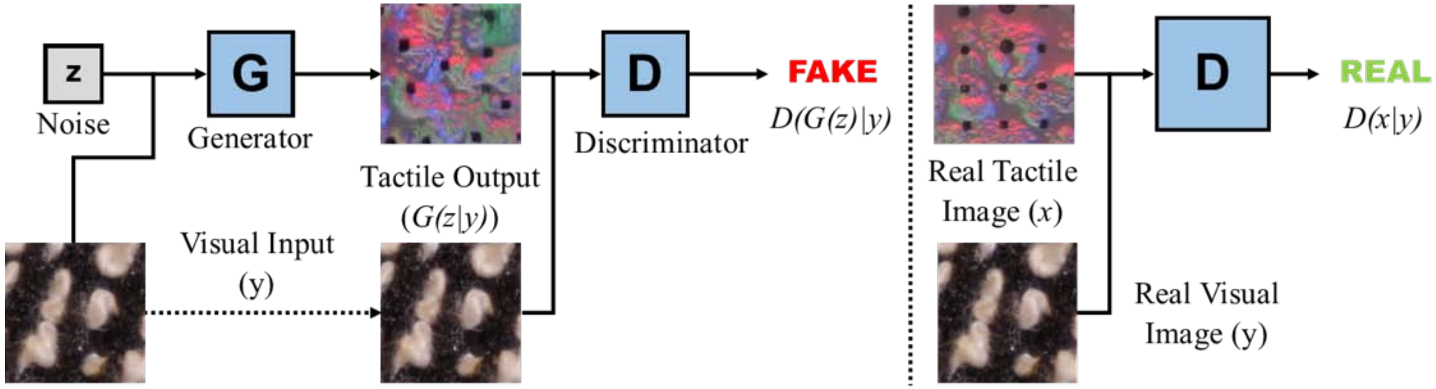


J. Lee, D. Bollegala , **S. Luo**, “Touching to See” and “Seeing to Feel”: Robotic Cross-modal Sensory Data Generation for Visual-Tactile Perception, ICRA 2019.

“Touch to See” and “Seeing to Feel”



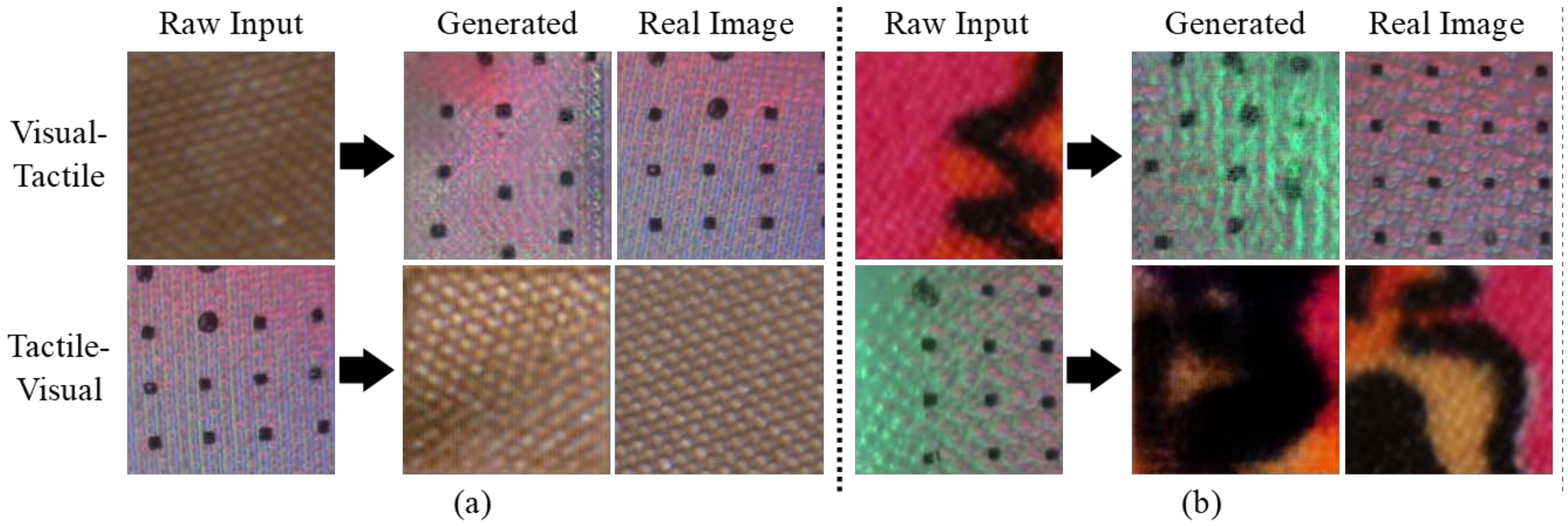
Tactile-to-Visual Network



Visual-to-Tactile Network

J. Lee, D. Bollegala , **S. Luo**, “Touching to See” and “Seeing to Feel”: Robotic Cross-modal Sensory Data Generation for Visual-Tactile Perception, ICRA 2019 (under review).

“Touch to See” and “Seeing to Feel”



(a) Ideal training images generating a consistent pattern

(b) Cloth set containing a dyed design showing difficulty in replicating a tactile-visual image

J. Lee, D. Bollegala , **S. Luo**, “Touching to See” and “Seeing to Feel”: Robotic Cross-modal Sensory Data Generation for Visual-Tactile Perception, ICRA 2019 (under review).

Interactive tactile perception

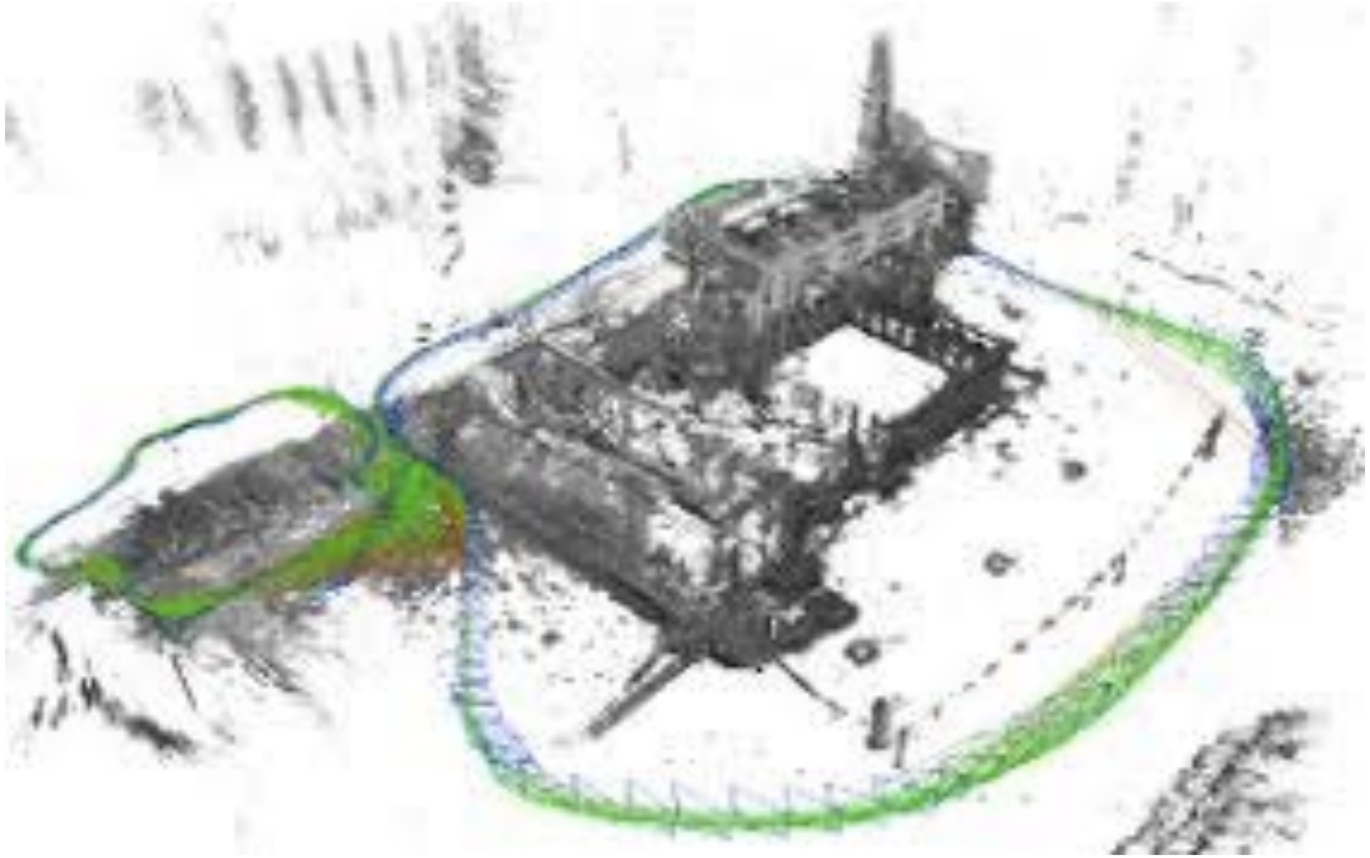
Interactive perception by interacting with objects

Press
Slip
Twist
Explore
Push
Grasping
Manipulation
…

PR2: www.willowgarage.com/pages/pr2

Interactive perception by interacting with objects

Classic SLAM: vision as input

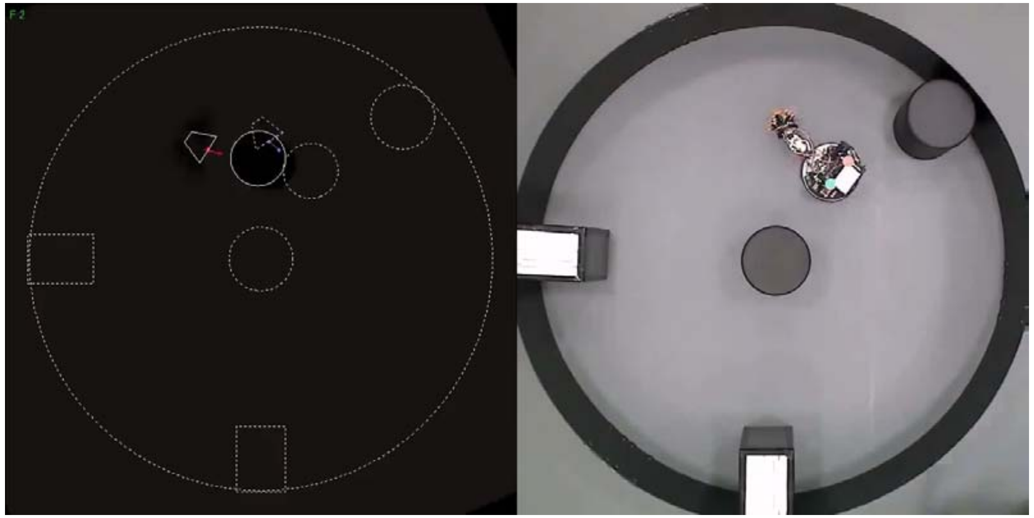


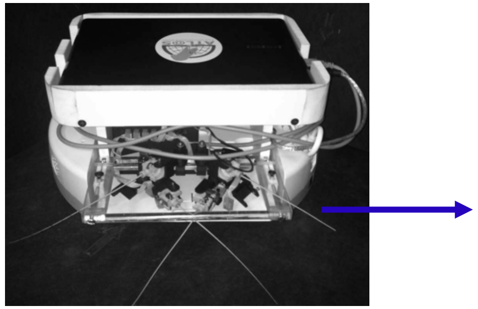
LiDAR

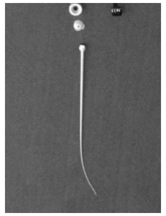
Cameras

Interactive perception by interacting with objects

Haptic SLAM



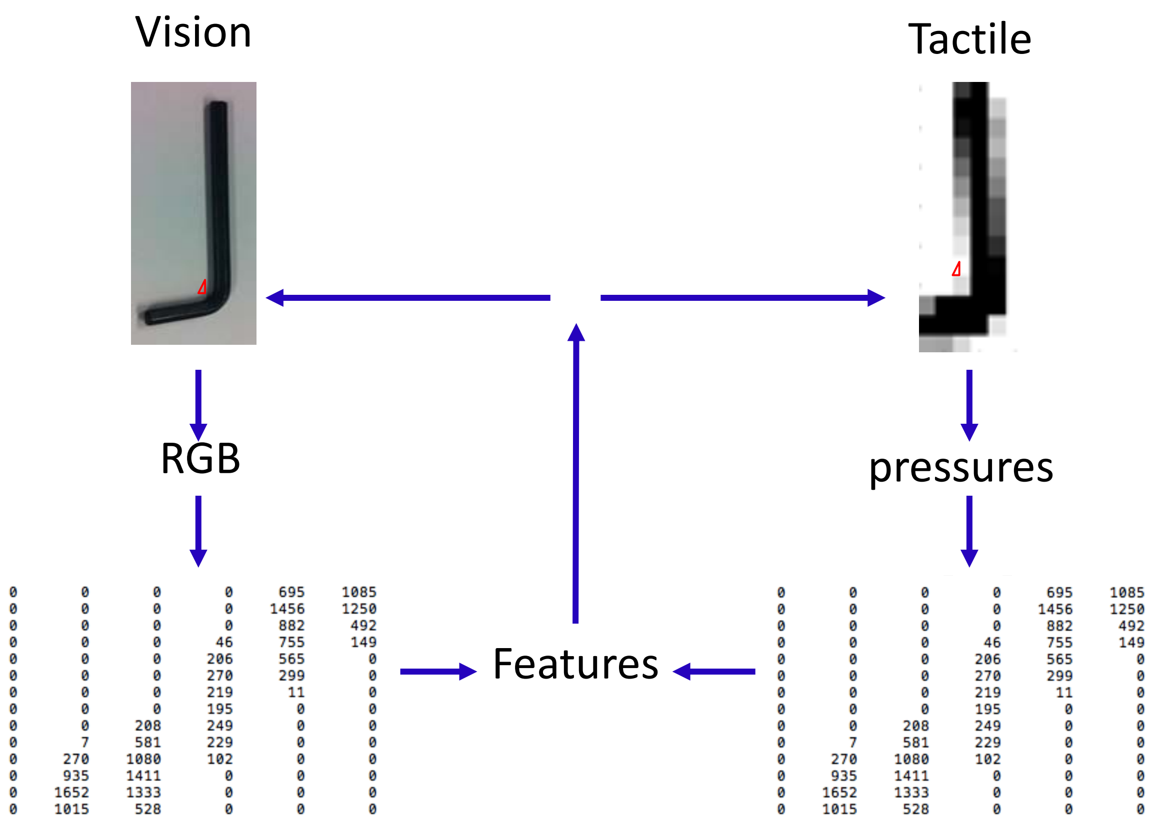




whisker
(dynamic tactile sensor)

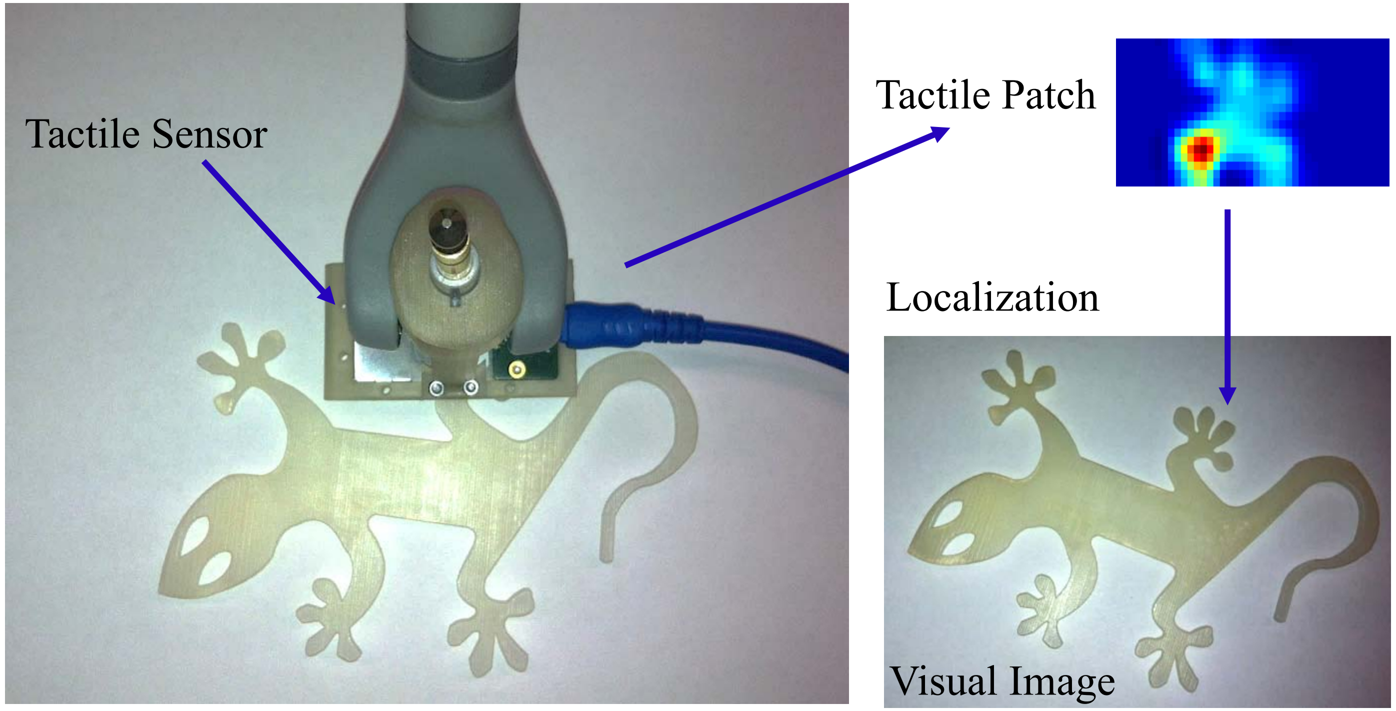
C. Fox, *et al*. “Tactile SLAM with a biomimetic whiskered robot”, *ICRA*, 2012.

Interactive perception by interacting with objects



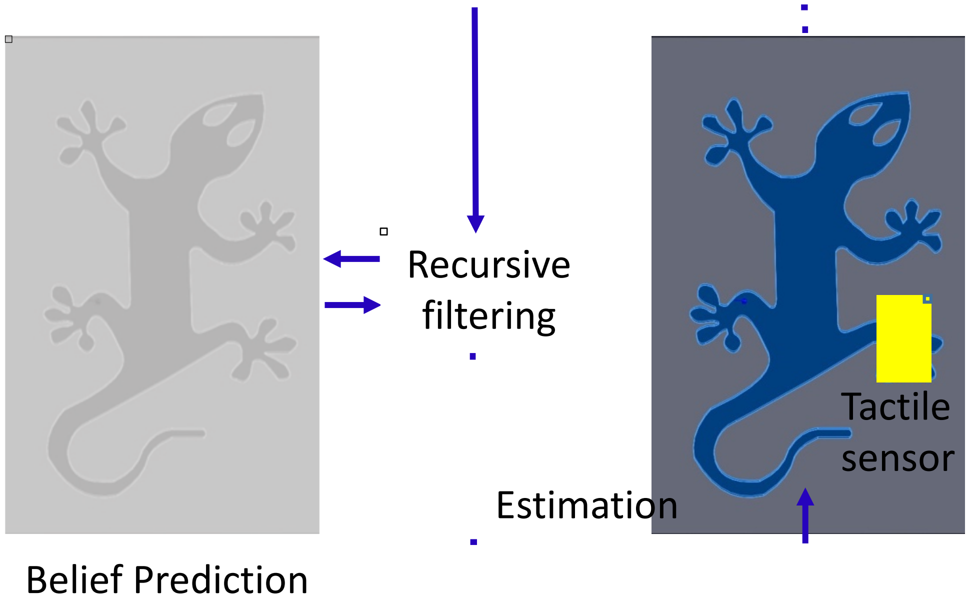
Interactive perception by interacting with objects

Experimental setup



Interactive perception by interacting with objects

Bayesian filtering framework



S. Luo, *et al*. "Localising the Object Contact through Matching Tactile Features with Visual Map", *ICRA*, 2015.

Interactive perception by interacting with objects

Bayesian filtering framework

Algorithm Bayes_filter($bel(x_{t-1}), u_t, z_t$**):**

for all x_t *do*

$\overline{bel}(x_t) = \int p(x_t|u_t, x_{t-1}) bel(x_{t-1}) dx_{t-1}$ ← Motion update

$bel(x_t) = \eta p(z_t|x_t) \overline{bel}(x_t)$ ← Overall update

endfor

return $bel(x_t)$

$bel(x_{t-1})$: belief at time t-1

u_t: sensor movement at t

z_t: senor measurement at t

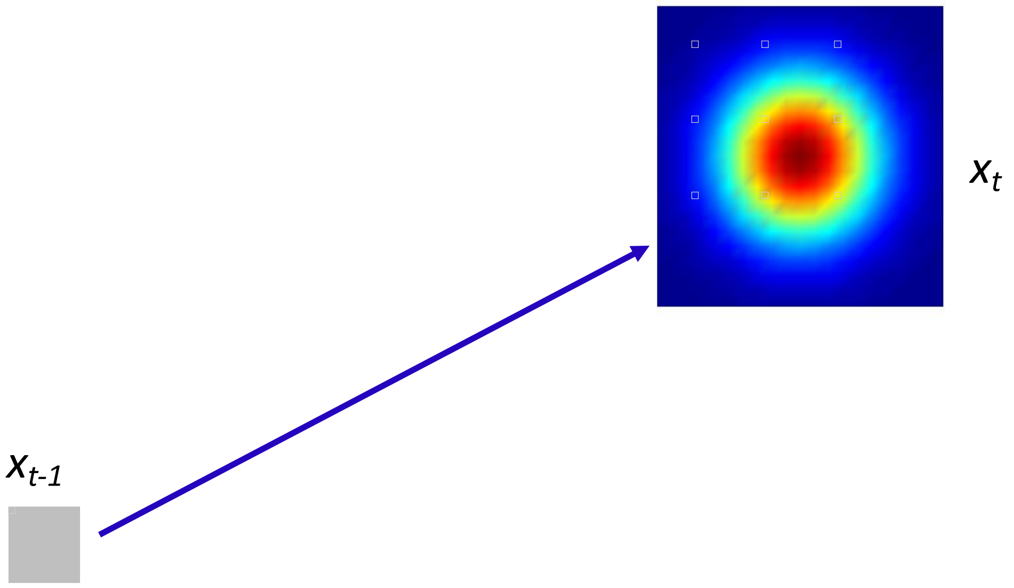
$\overline{bel}(x_t)$: belief after control update

$bel(x_t)$: belief after measurement update

S. Luo, *et al*. "Localising the Object Contact through Matching Tactile Features with Visual Map", *ICRA*, 2015.

Interactive perception by interacting with objects

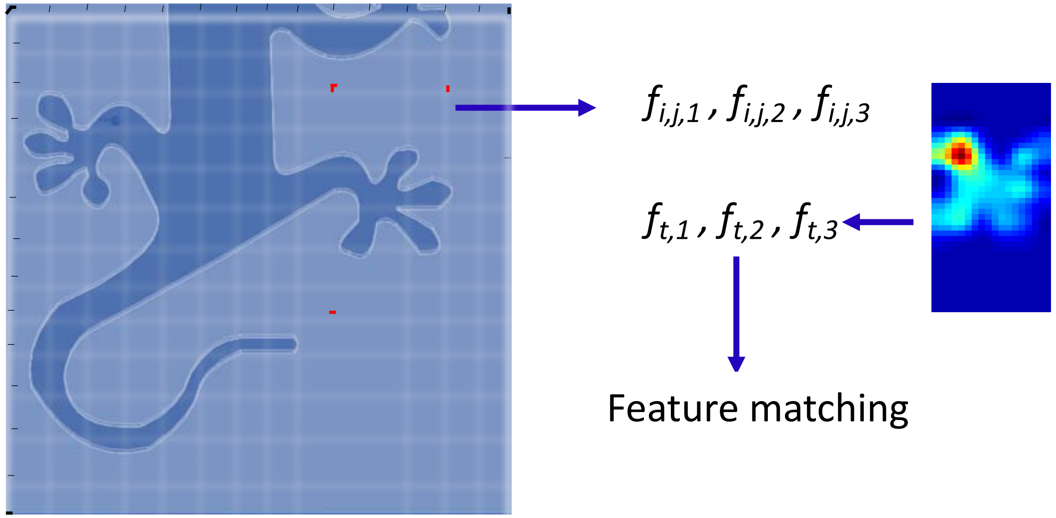
Motion model/Control update



S. Luo, *et al*. "Localising the Object Contact through Matching Tactile Features with Visual Map", *ICRA*, 2015.

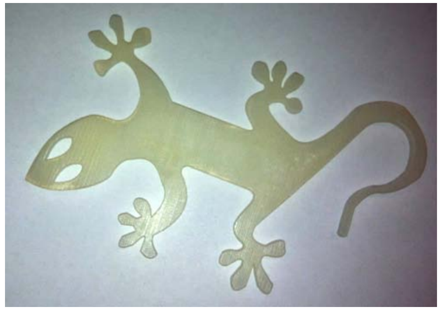
Interactive perception by interacting with objects

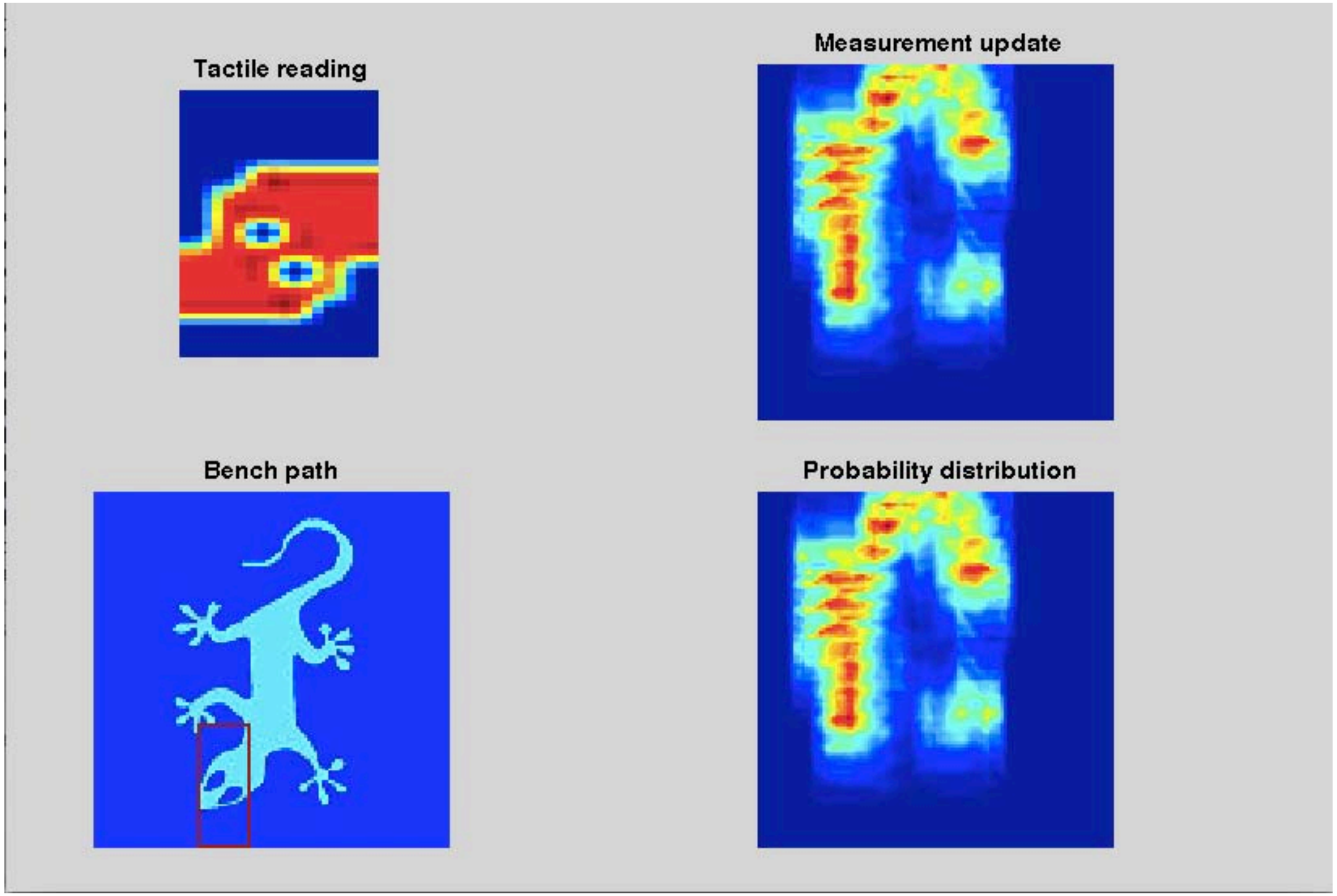
Feature-based measurement models/Measurement update



S. Luo, *et al*. “Localising the Object Contact through Matching Tactile Features with Visual Map”, *ICRA*, 2015.

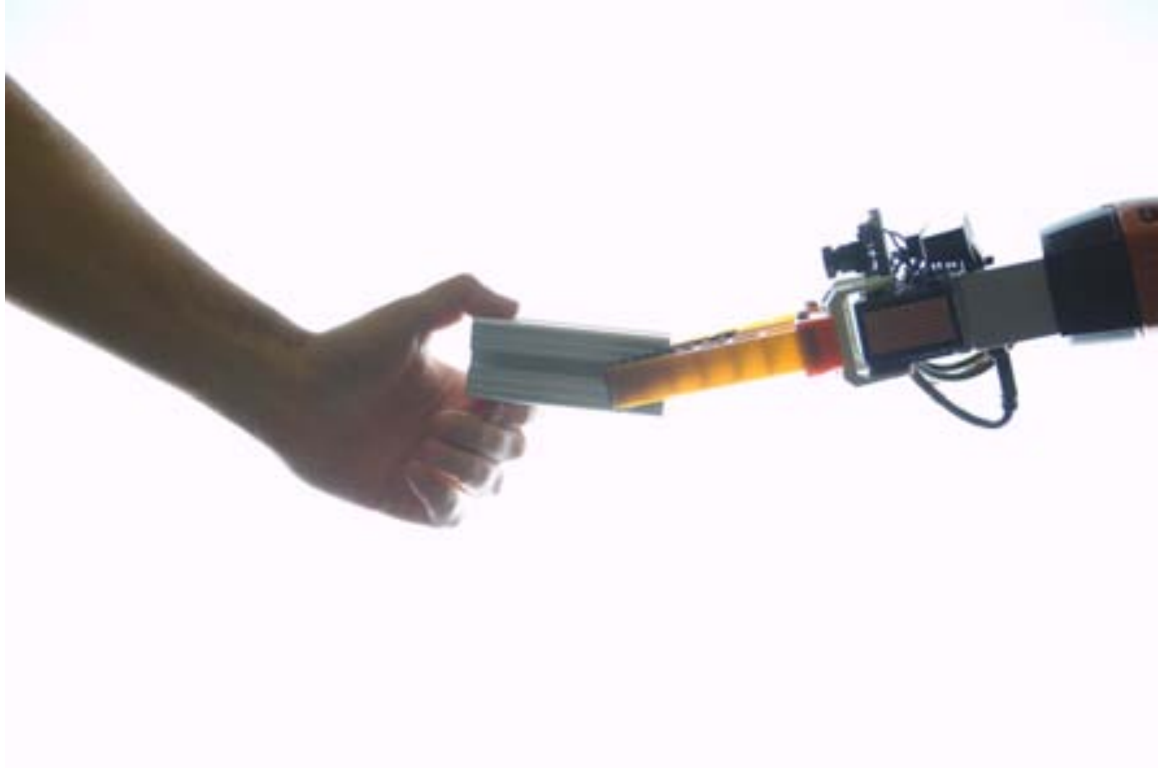
Interactive perception by interacting with objects





S. Luo, *et al*. “Localising the Object Contact through Matching Tactile Features with Visual Map”, *ICRA*, 2015.

Leveraging Action in Perception and Perception in Action



Picture credit:

Benjamin Schneiders, smARTLab

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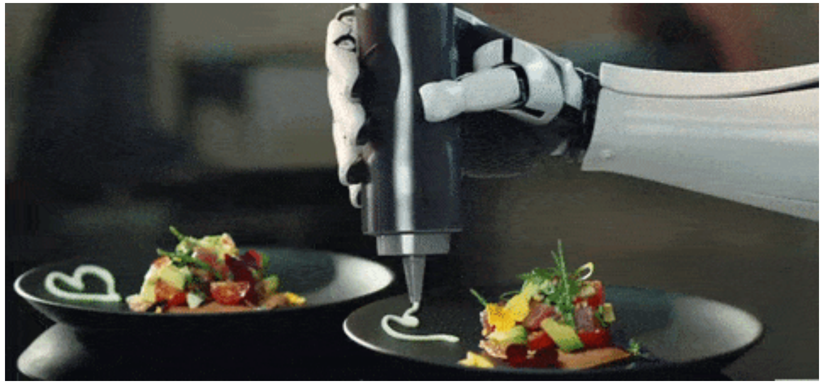
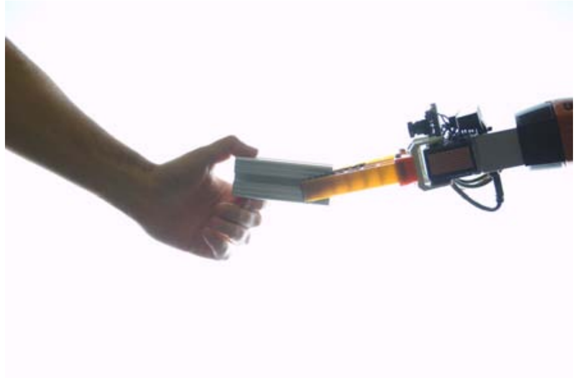
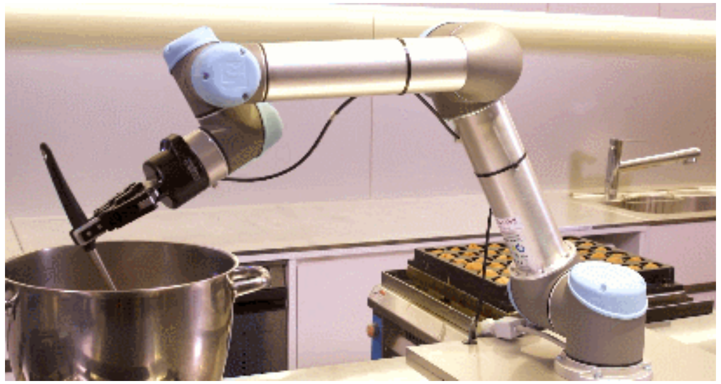
Leveraging Action in Perception and Perception in Action







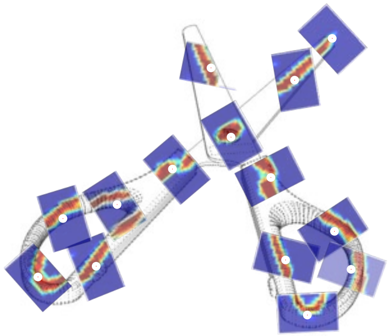
https://www.roboticgizmos.com
https://www.digitalspy.com

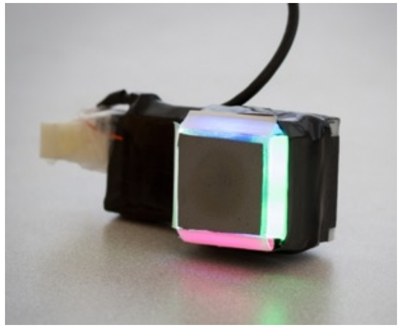
Summary

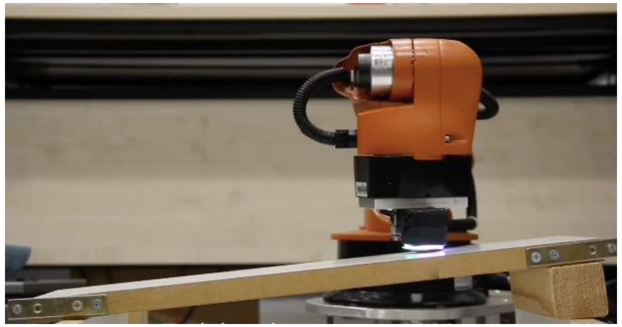
- ➢ Goal: Robots perceive the physical world

- ✓ Make use of high-resolution camera-based tactile sensors for perception tasks
- ✓ Tactile object representations of object local and global shapes, textures and poses
- ✓ Multimodal and Cross-modal visual-tactile perception

- ❑ Future: Intelligent perception through interaction







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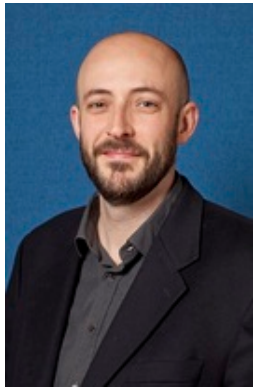

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University of Liverpool

Prof Andy Cooper
University of Liverpool

Prof Tony Cohn
University of Leeds

Thank you

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