Material-integrated Intelligence for Robot Autonomy

Nikolaus Correll
University of Colorado at Boulder

Robotics then and now

1968

2016

What’s missing?

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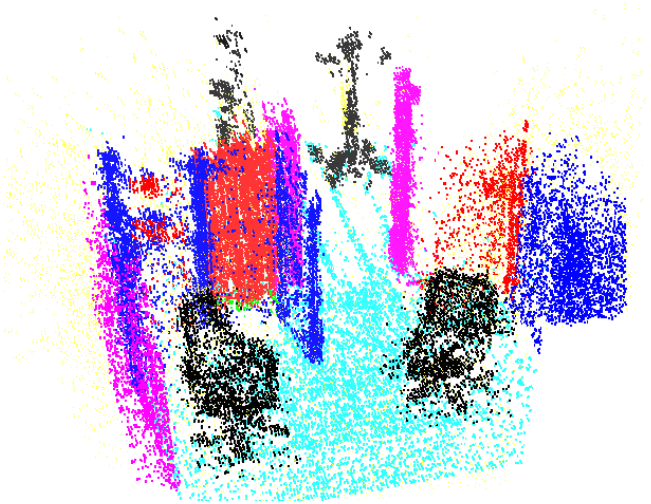
Components of Robotic Systems



1. Perception

2. Planning and Control

Robotics

3. Tight integration of sensing, Computation and actuation

Robotic Materials

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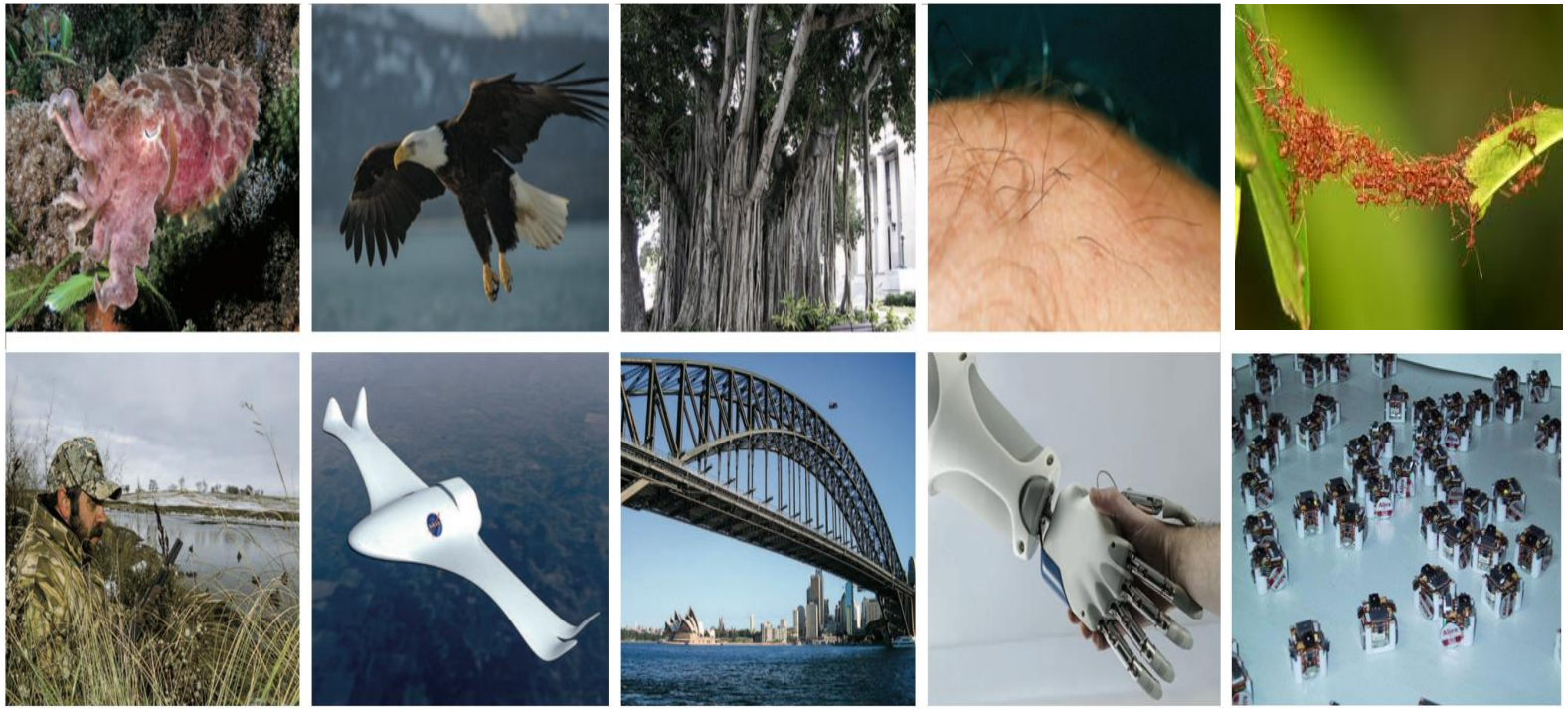
Robotic Materials



Tight integration of sensing, actuation and computation *inside* the material

M. McEvoy and N. Correll. Materials that couple Sensing, Actuation, Computation and Communication. *Science*, 2015.

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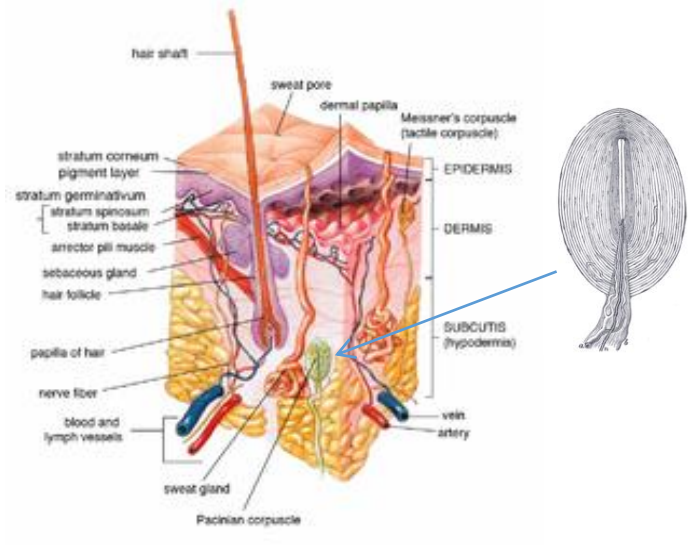
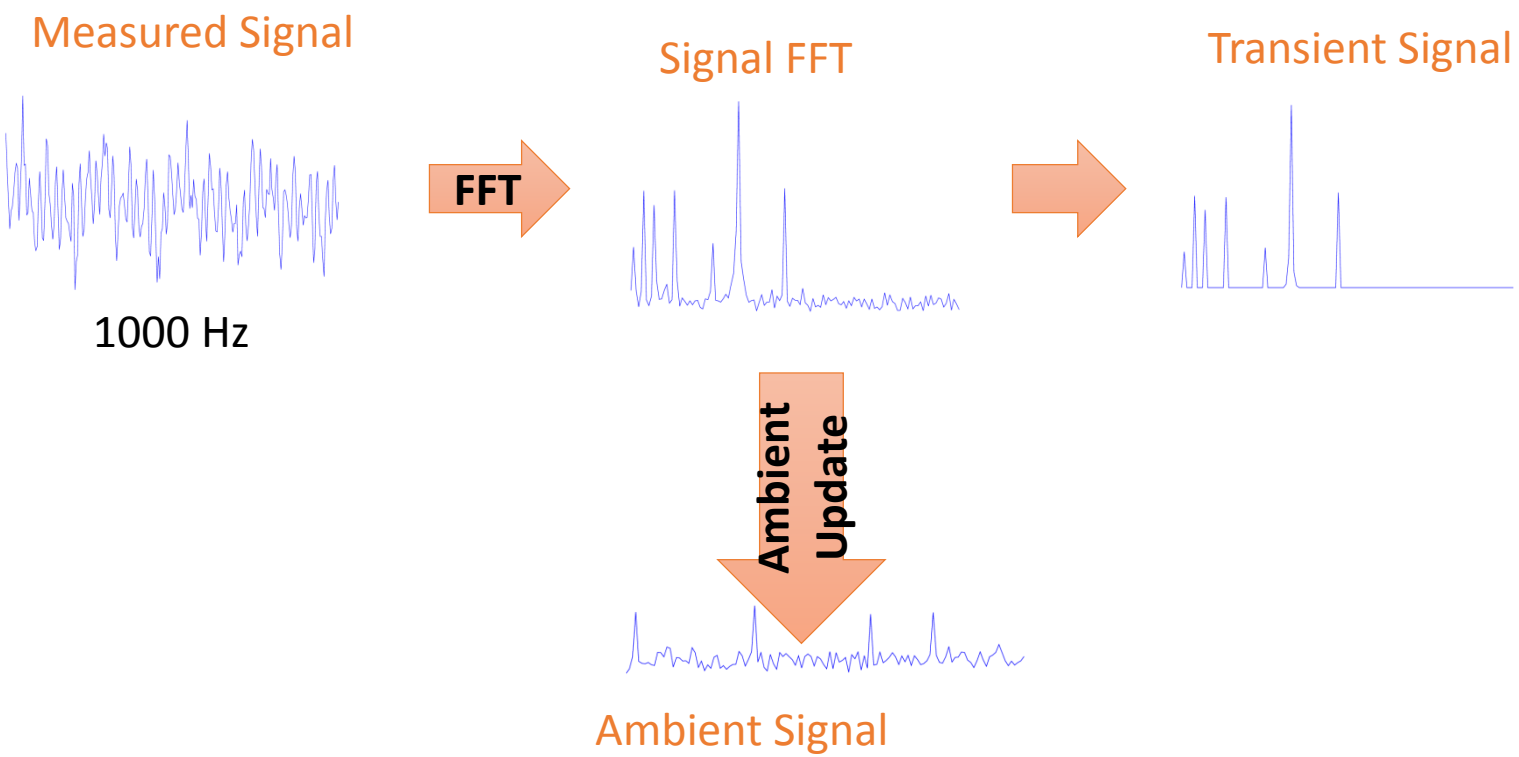
Example I: Soft Sensing Skin





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Real-time localization and routing

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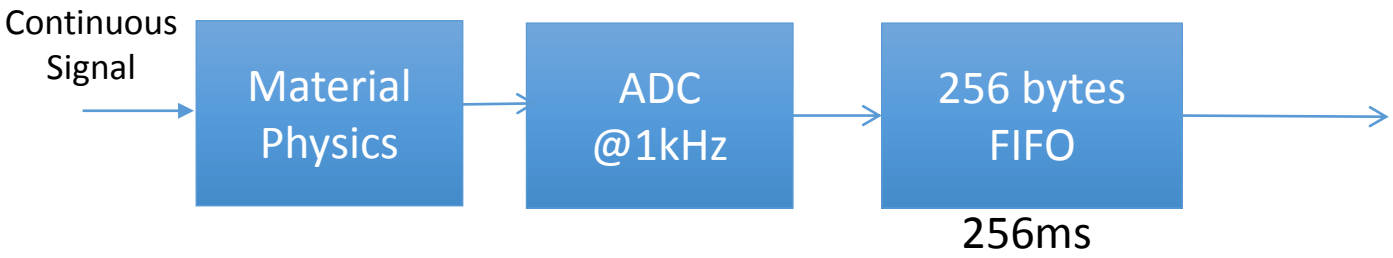
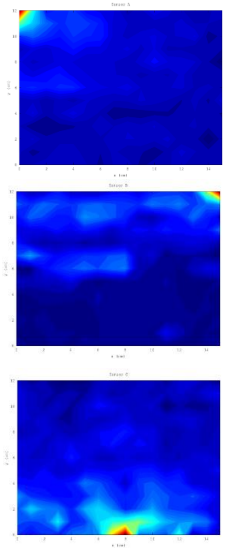
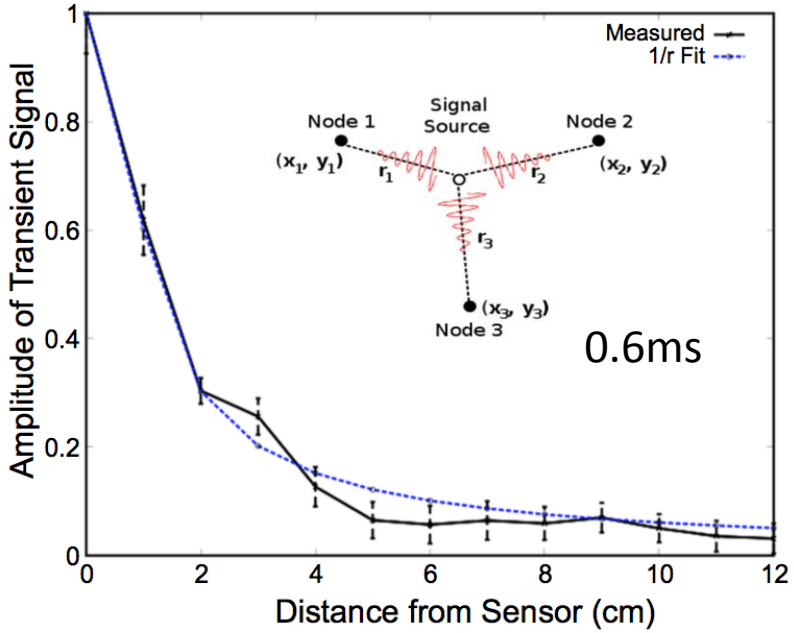
Discrete Computation: DFT and filtering



$$S(f,t) = \sum_{n=0}^{N-1} x_n \cdot e^{-j2\pi fn/N}$$

15.9ms on Atmel Xmega 128A3





$$A(f,t) = \alpha S(f,t) + (1-\alpha)A(f,t-1)$$

$$T(f,t) = \min(S(f,t) - A(f,t), 0)$$

D. Hughes, N. Correll (2015): Texture Recognition and Localization in Amorphous Robotic Skin. In: *Bioinspiration & Biomimetics*, 2015.

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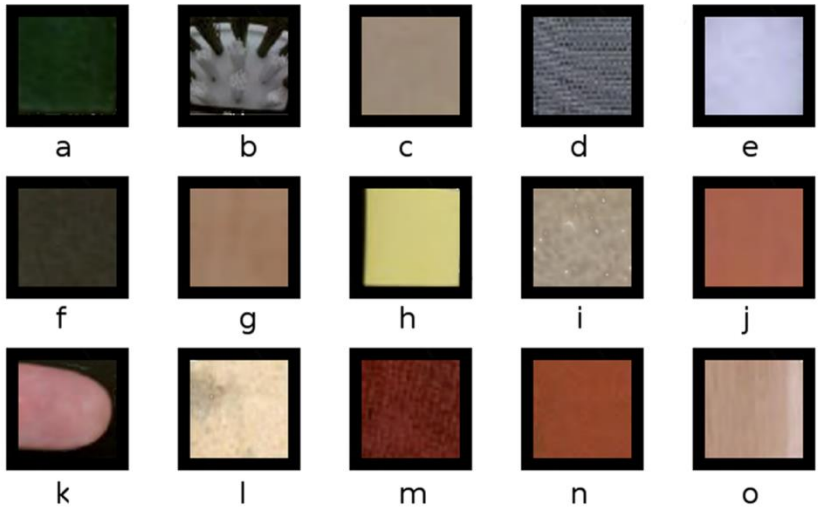
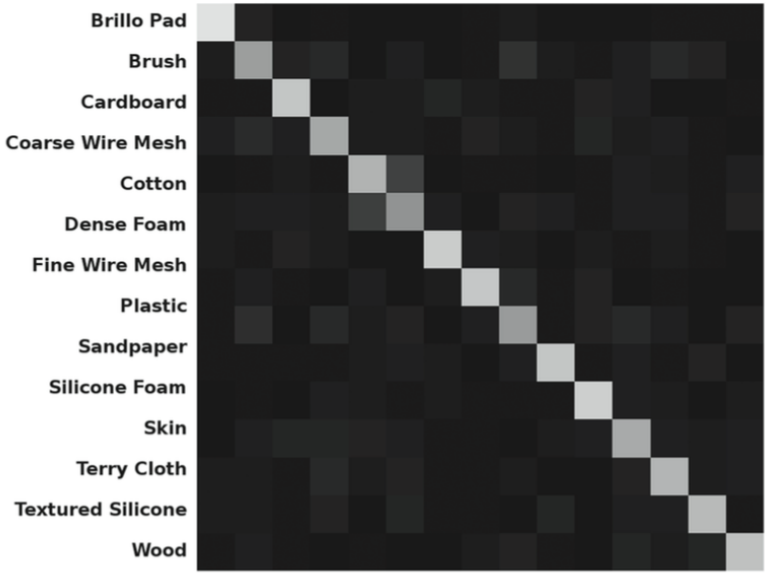
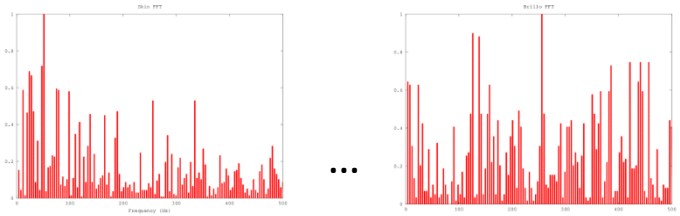
Discrete Computation: Classification





71.7% accuracy
100 samples
10-fold cross-validation

DFT Spectrum



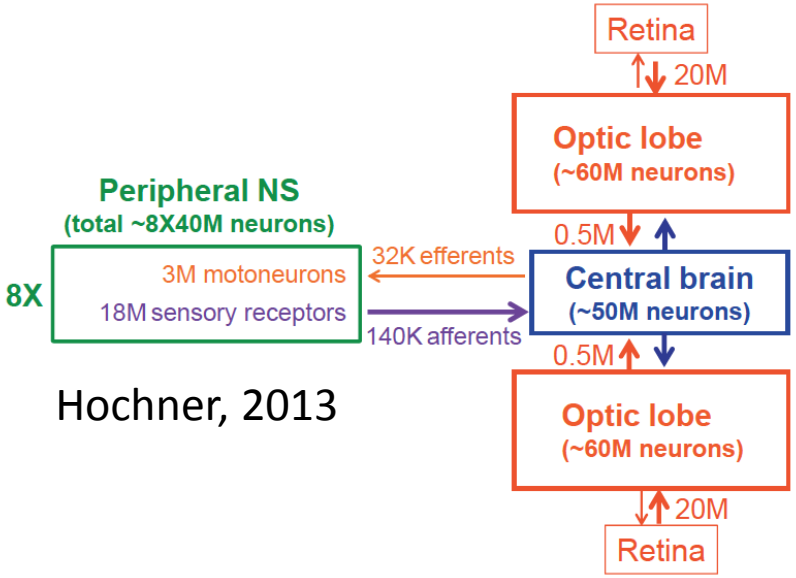
Human Skin ... Brillo

$$y_t(X) = g\left(w_0 + w_1X_1 + X_2f_2 \ldots + w_nX_n\right)$$

Linear regression
15*128 = 1920 weights
0.6ms

Example II: Shape change by Variable Stiffness

- Octopus: No skeleton -> <u>variable stiffness</u> using muscular hydrostats
  Kier, 1985
- Arm can make autonomous movements
  Graziadei, 1965
- Redundant mechanisms pose great load on motor control system
  Gutfreund, 2006
- <u>2/3rds of the animal's neurons in arms</u> (peripheral nerve cord)
  Hochner, 2013



Hochner, 2013

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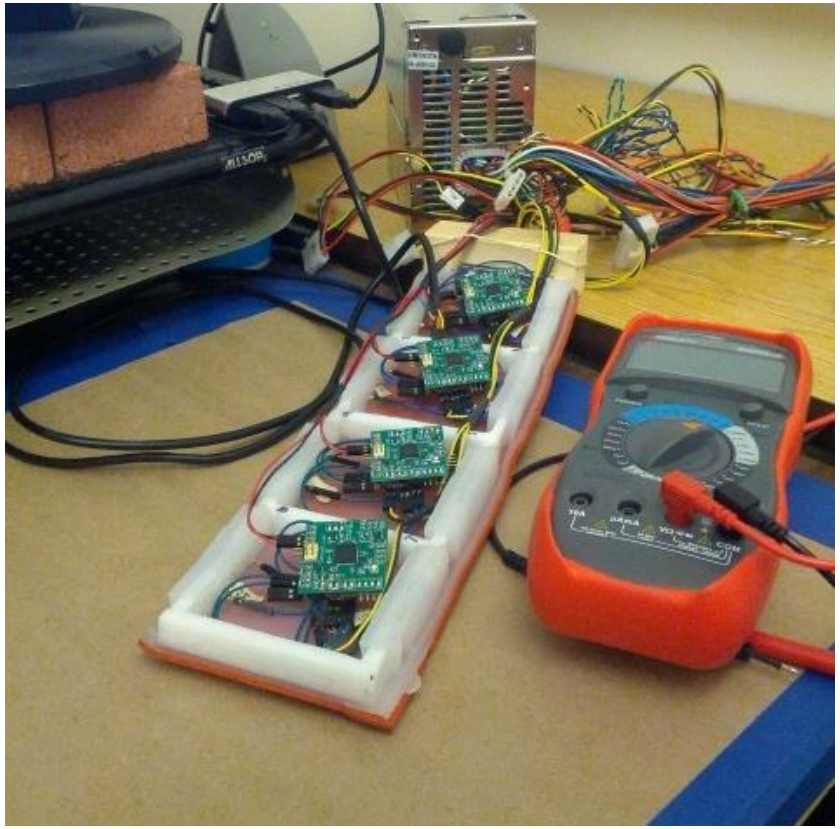
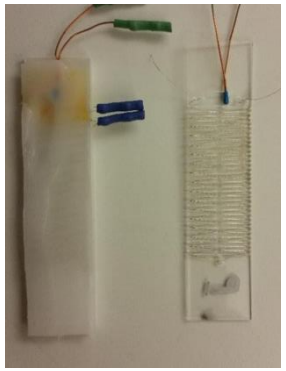
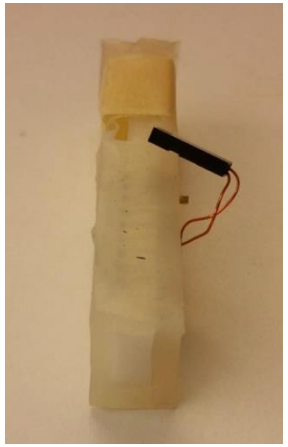
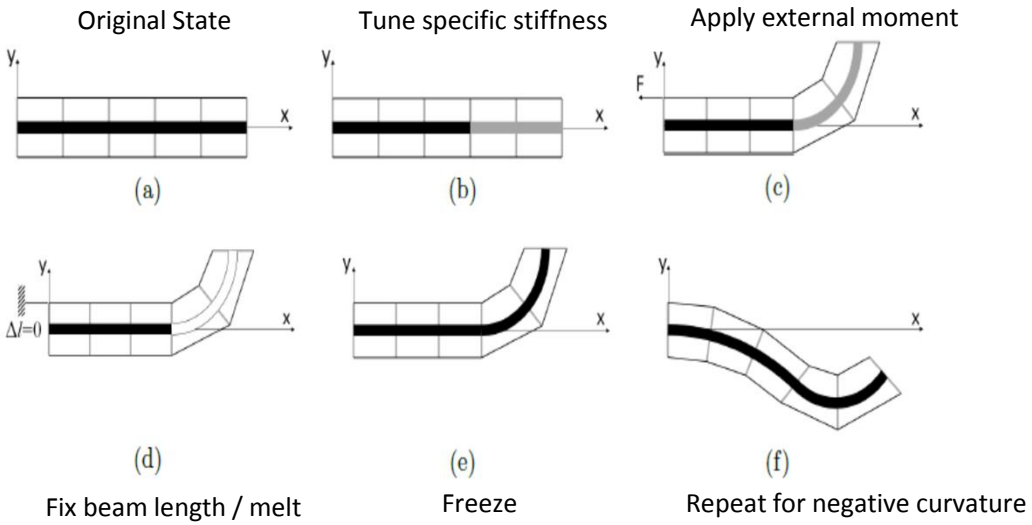
Variable Stiffness beam with embedded computation









M. A. McEvoy, N. Correll (2014): "Thermoplastic variable stiffness composites with embedded, networked sensing, actuation, and control. In: Journal of Composite Materials.

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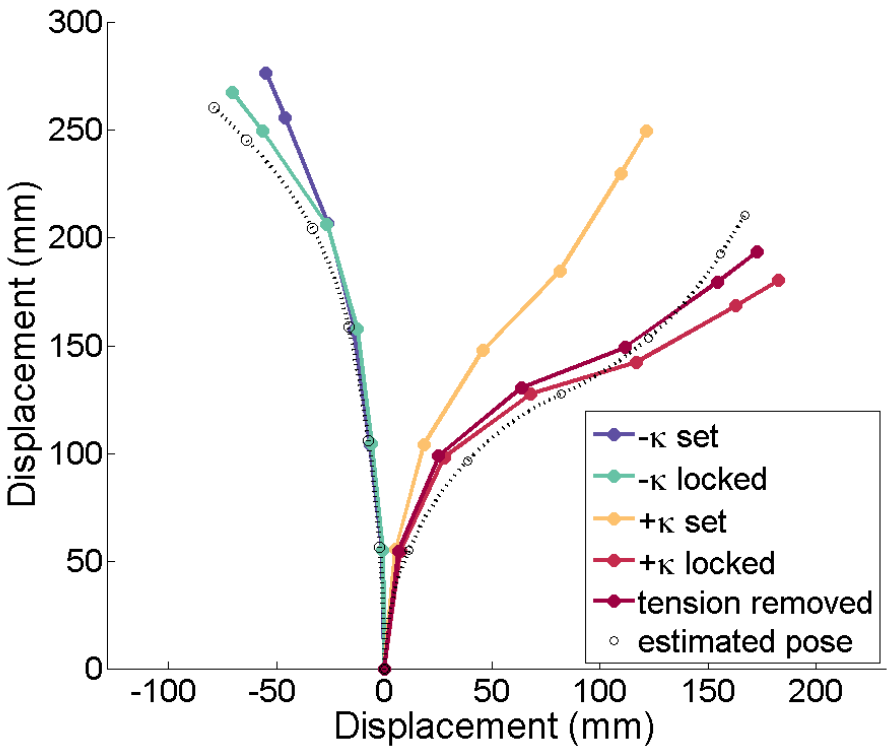
Experimental Results



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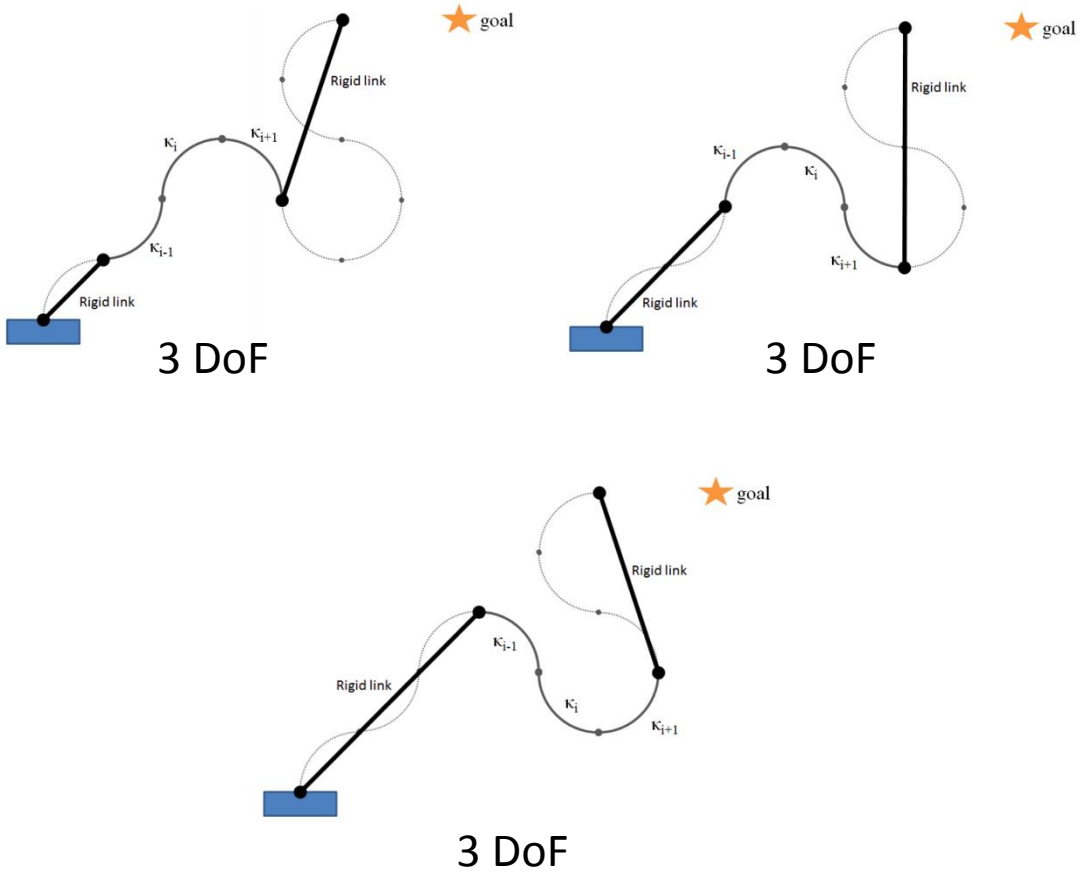
Distributed Computation of Matrix Inverse

- Distributed algorithm requires O(log N) time
- Problem: requires $O(N^4)$ computers
- Idea: reduce arm to multiple M<<N DoF systems and solve sequentially



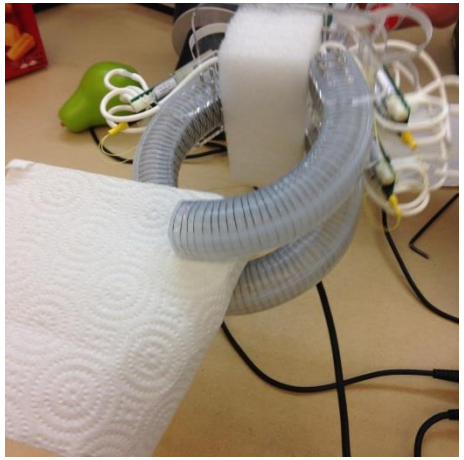
M. A. McEvoy, N. Correll (2016): Distributed Inverse Kinematics for Shape-Changing Robotic Materials . In:3rd International Conference on System-integrated Intelligence: New Challenges for Product and Production Engineering , Paderborn, Germany. (Best Paper)

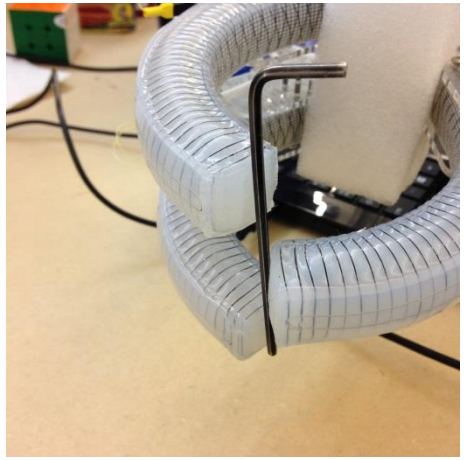
Example III: Grasping

Power grasps (easy)

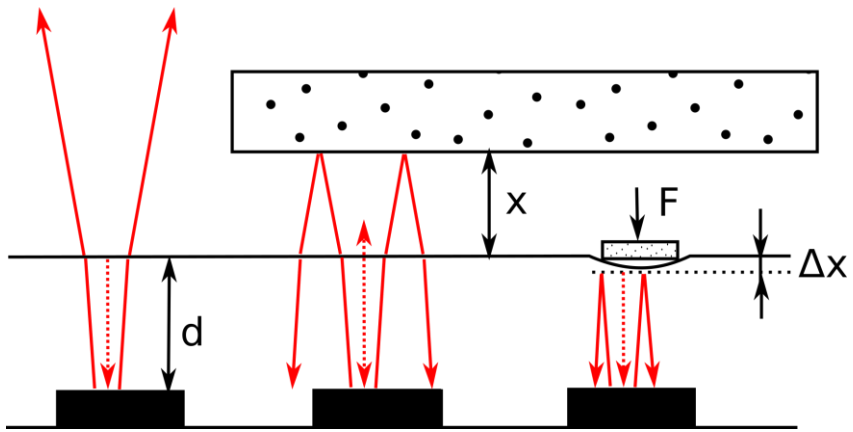
medium

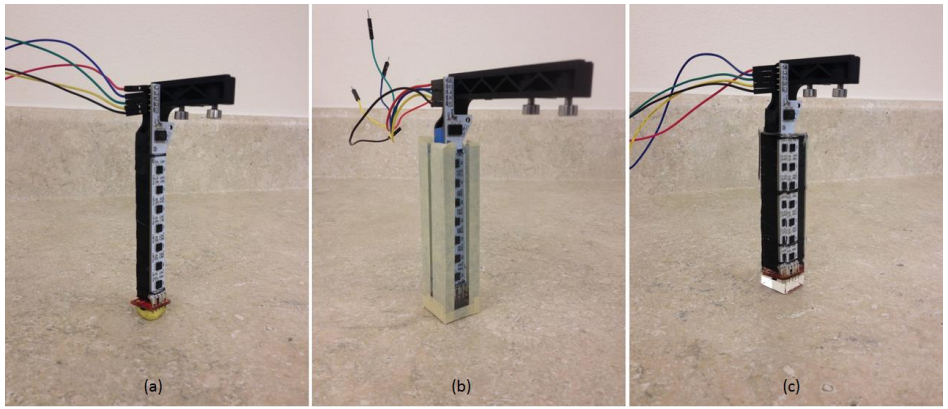
Pinching grasps (hard)

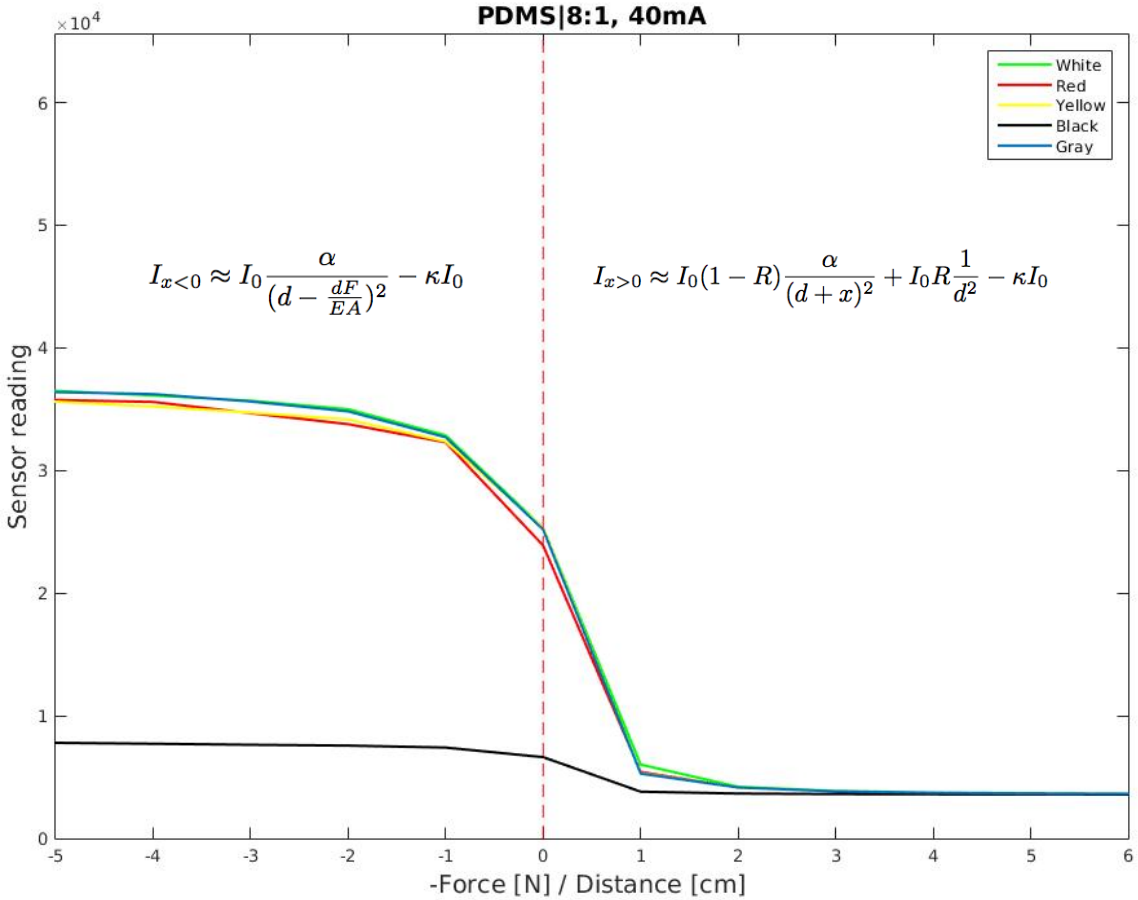




Combined distance and force sensing



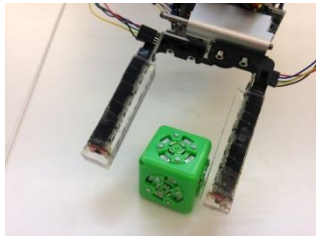




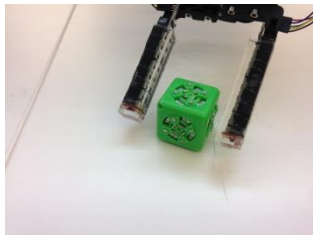
R. Patel and N. Correll. Integrated force and distance sensing for robotic manipulation using elastomer-embedded commodity proximity sensors. ``Robotics: Science and Systems'' (RSS), 2016.

Tactile and distance sensing during grasping

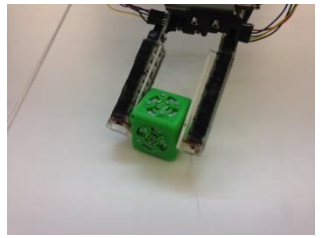
1. Approach



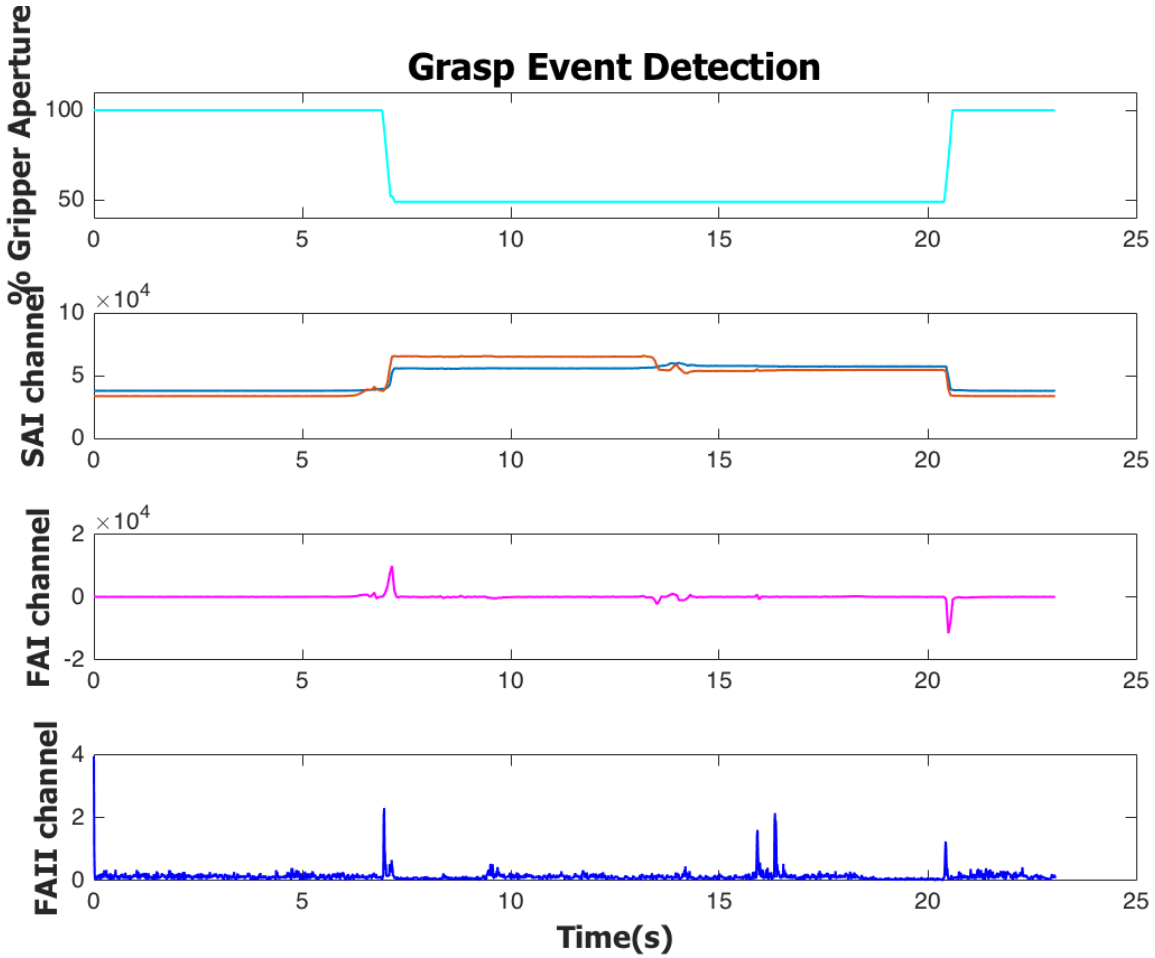
2. Align

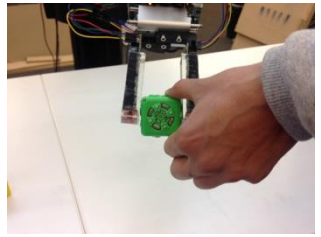


3. Contact

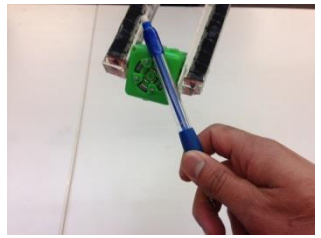


4. Loading





5. Disturbance (wrench)



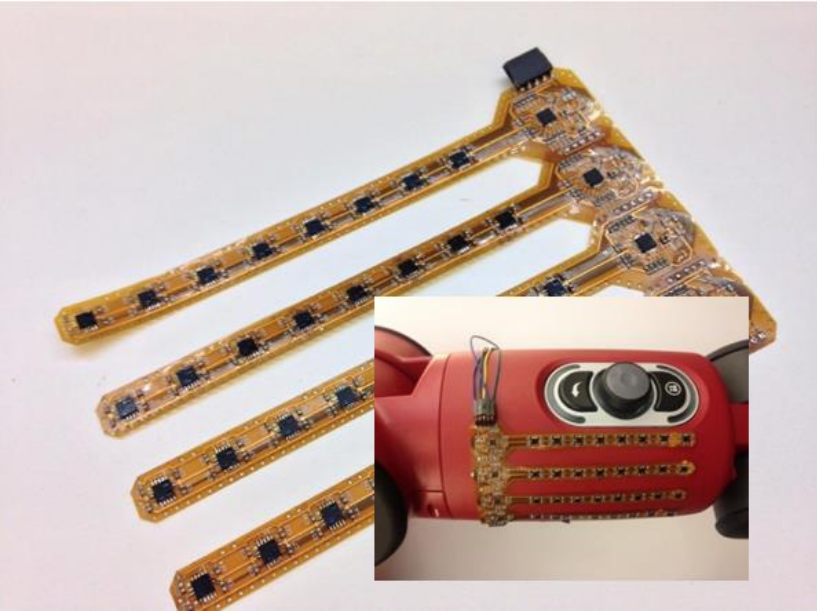
6. Disturbance (tapping)

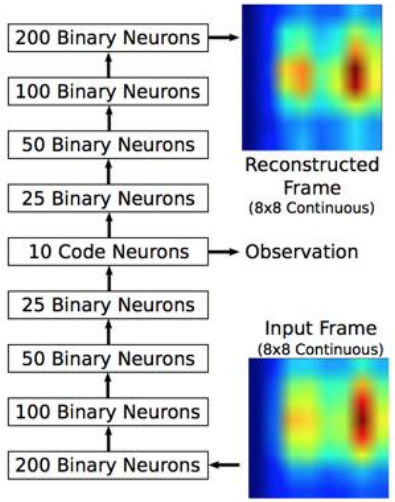
7. Replacement

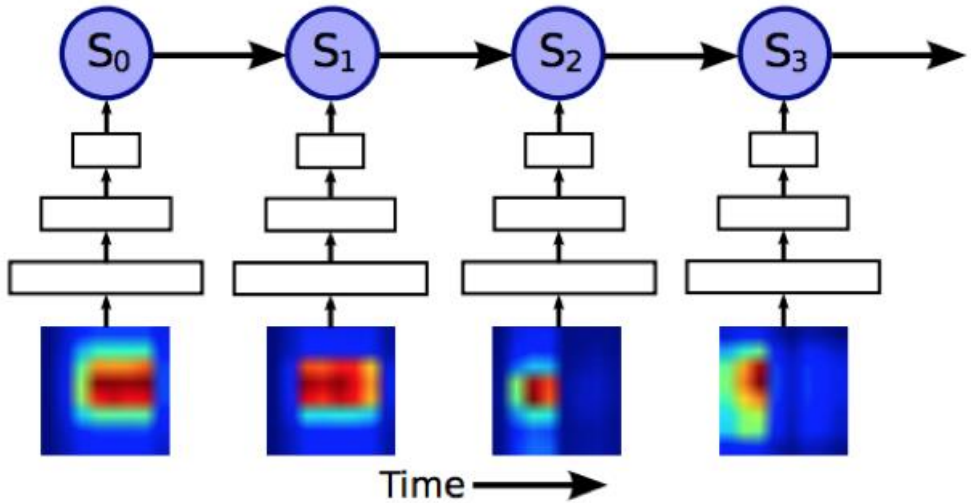
8. Release

R. Patel, J. Canardo Alestuey and N. Correll. Improving grasp performance using in-hand proximity and force sensing. Int. Symposium on Experimental Robotics (ISER), 2016.

Whole-body sensing: social touch and collision avoidance



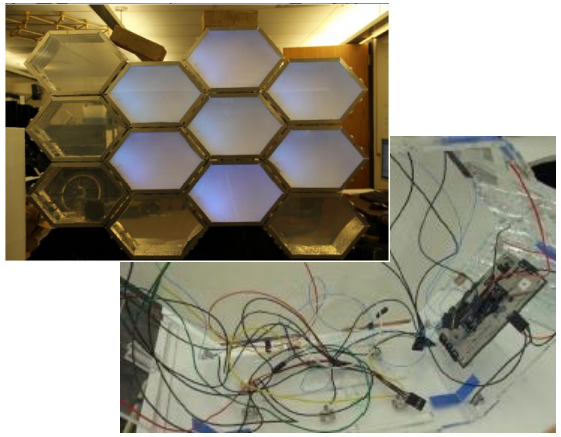


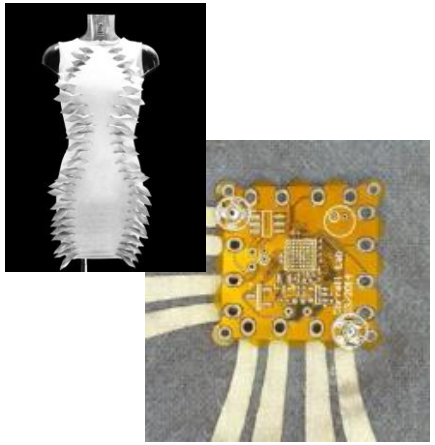


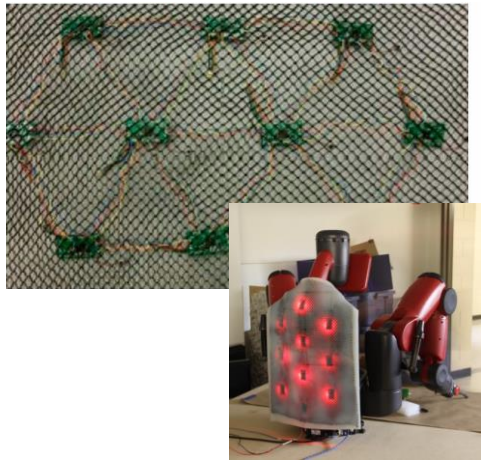
Actual Labels \ Classified Label	a	b	c	d	e	f	g	h	i	j	k	l	m	n
grab (a)	**83**	1	4	0	4	0	13	1	0	0	74	0	0	0
hit (b)	0	**61**	0	19	0	19	0	0	0	36	0	1	19	0
massage (c)	6	0	**77**	0	1	0	0	7	10	0	7	0	0	10
pat (d)	0	7	0	**45**	1	1	1	0	2	4	0	3	29	2
pinch (e)	0	1	2	1	**67**	4	3	0	1	1	5	3	1	5
poke (f)	0	7	0	1	10	**57**	2	0	1	2	1	0	2	1
press (g)	13	0	4	0	20	6	**75**	17	10	2	8	4	2	0
rub (h)	0	0	16	1	2	0	6	**37**	12	0	1	20	1	5
scratch (i)	3	0	6	2	2	0	1	13	**22**	0	0	4	0	5
slap (j)	0	33	0	26	1	5	0	0	0	**65**	0	1	29	0
squeeze (k)	14	0	2	0	3	0	8	4	3	0	**23**	0	0	0
stroke (l)	1	0	2	5	7	2	11	27	18	0	0	**67**	4	5
tap (m)	0	8	0	20	0	15	0	0	0	9	0	2	**29**	3
tickle (n)	0	2	7	0	2	11	0	14	41	1	0	15	4	**84**

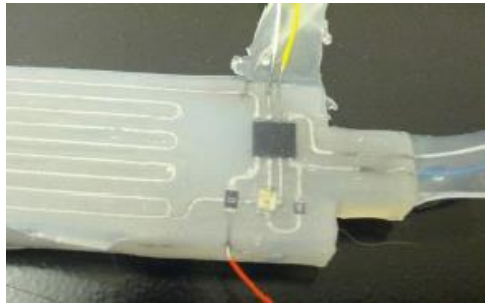
D. Hughes, N. Farrow, H. Profita, N. Correll (2015): Detecting and Identifying Tactile Gestures using Deep Autoencoders, Geometric Moments and Gesture Level Features. ACM International Conference on Multimodal Interaction, Recognition of Social Touch Gestures Challenge, Seattle,

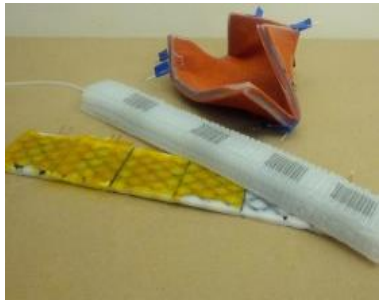
Key Challenge: Manufacturing Robotic materials economically

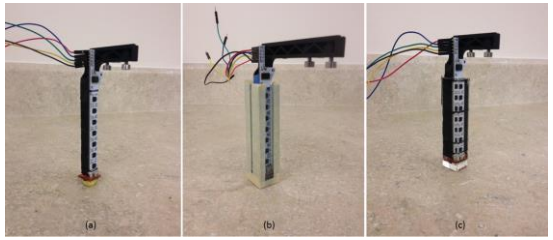












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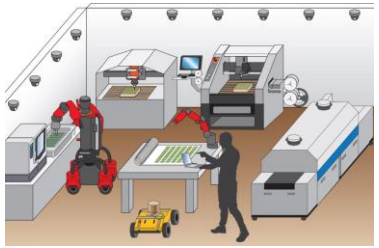
Conclusion

- **Distributed** solutions for classification, optimization and control problems
- **Scalable** with the number of elements
- **Robust** against failures of individual elements
- Distributed, Scalable, Robust: Autonomous Material
- Challenges
  - What's the underlying science of autonomous materials
  - What kind of autonomy would otherwise not possible
  - What are the low-hanging fruits relevant to industry now



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