Material-integrated Intelligence for Robot Autonomy

Nikolaus Correll
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Robotics then and now

1968

2016

Whats missing?

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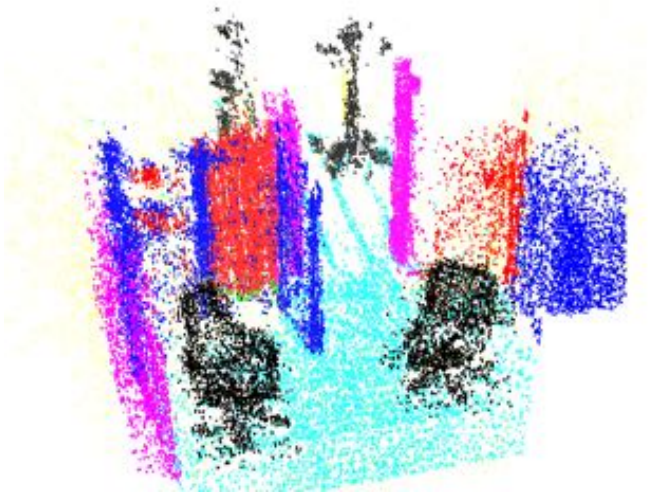
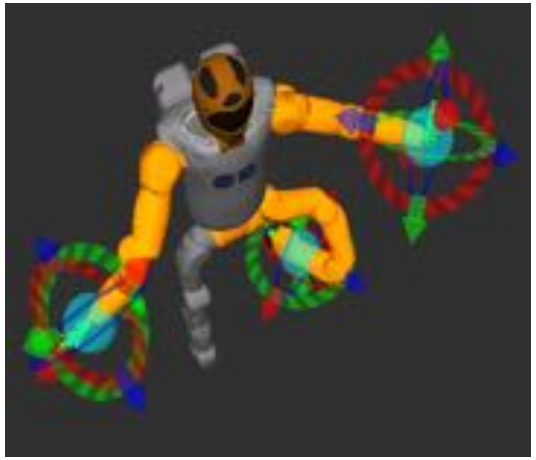
Components of Robotic Systems





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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Advantages of distributed computation

- *High-bandwidth sensing*: soft robotic skin
- *High-speed Feedback control*: object manipulation
- *Distributed computation:* optimization and classification

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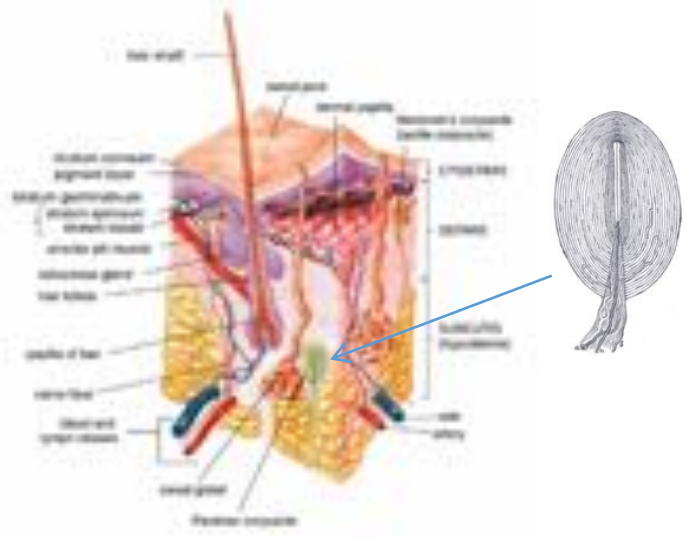
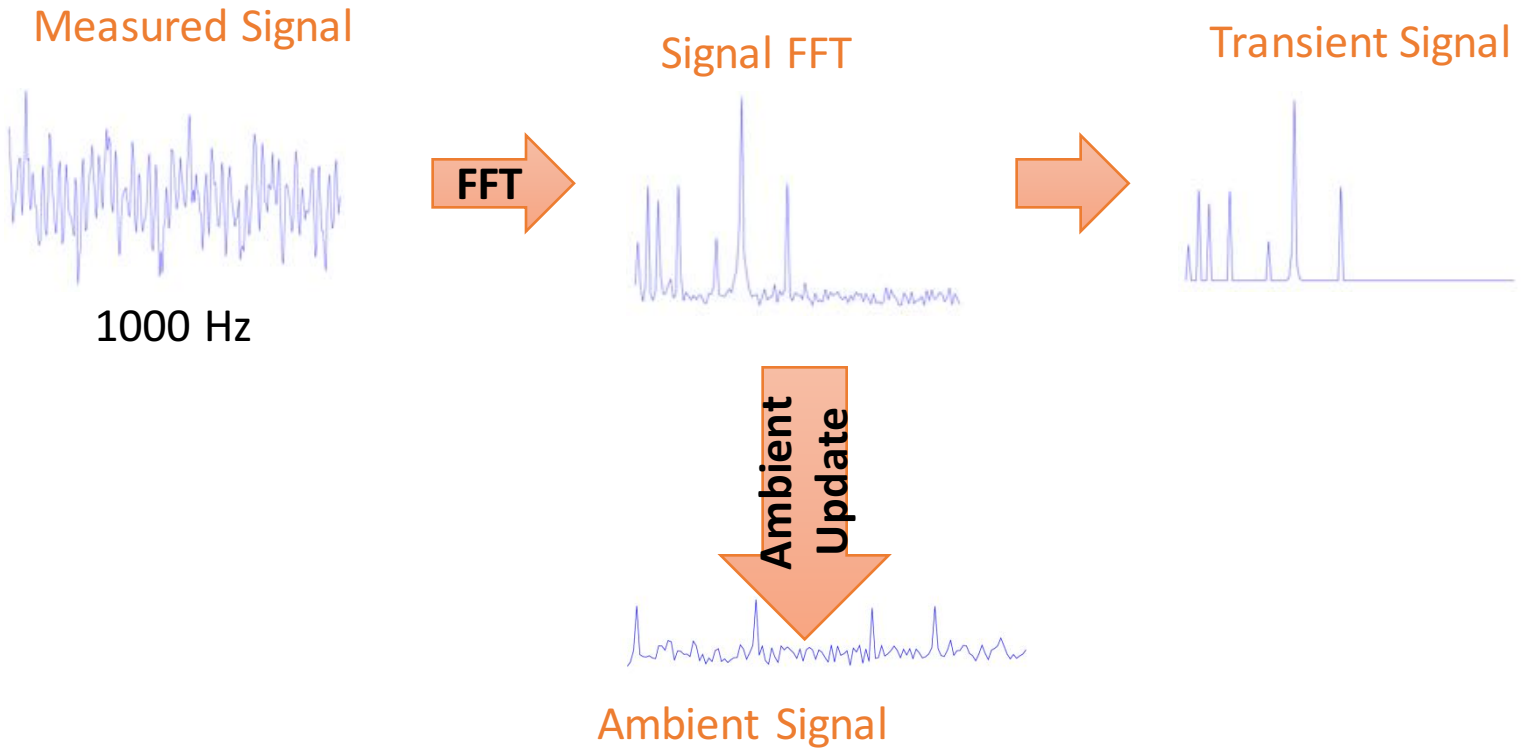
Example I: Soft Sensing Skin





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

Real-time localization and routing

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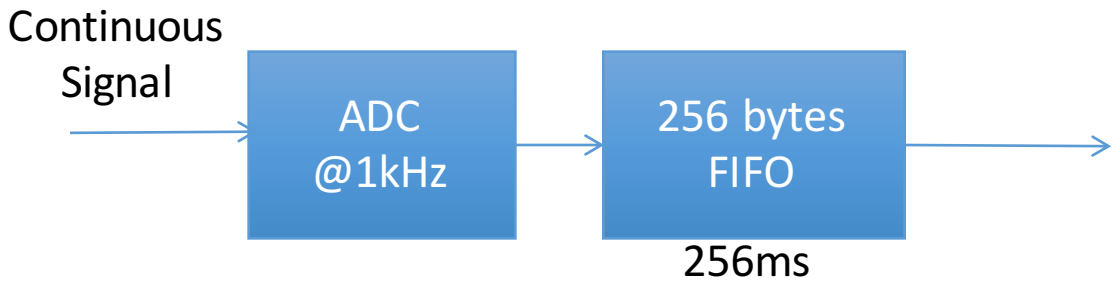
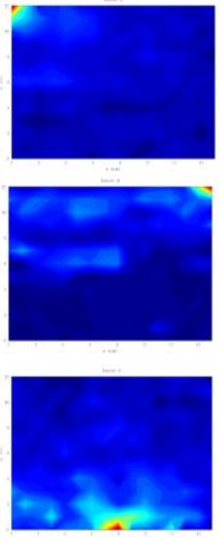
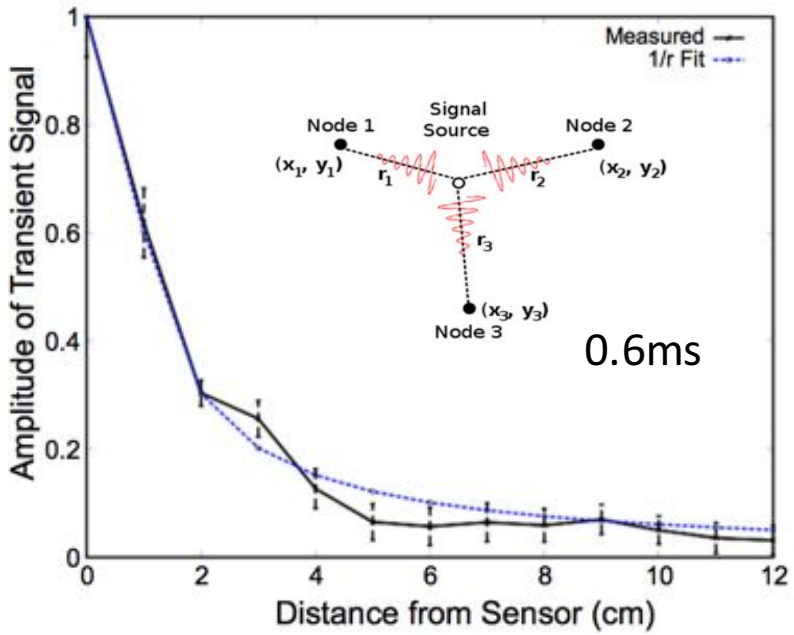
Discrete Computation: DFT and filtering



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

15.9ms on Atmel Xmega 128A3





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

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

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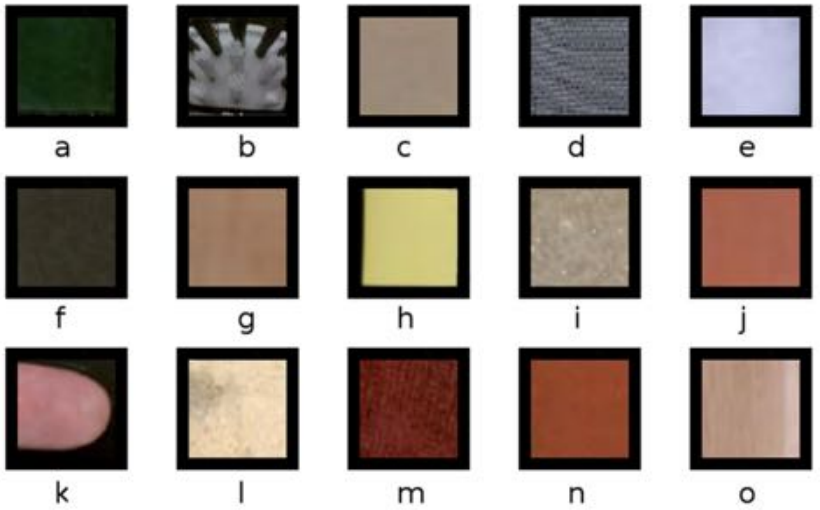
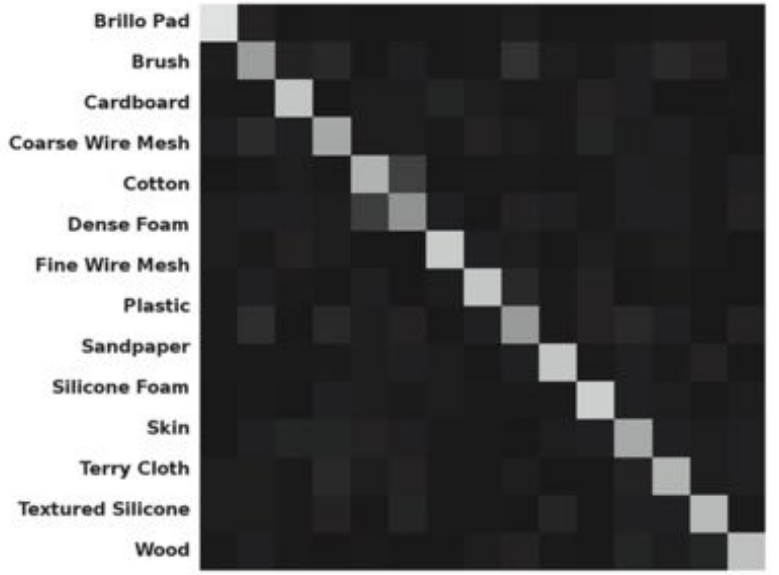
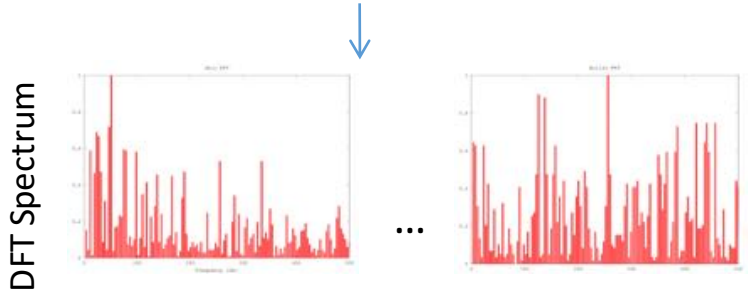
Discrete Computation: Classification





71.7% accuracy
100 samples
10-fold cross-validation



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

Linear regression
15*128 = 1920 weights
0.6ms

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Example II: Shape change by Variable Stiffness

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.

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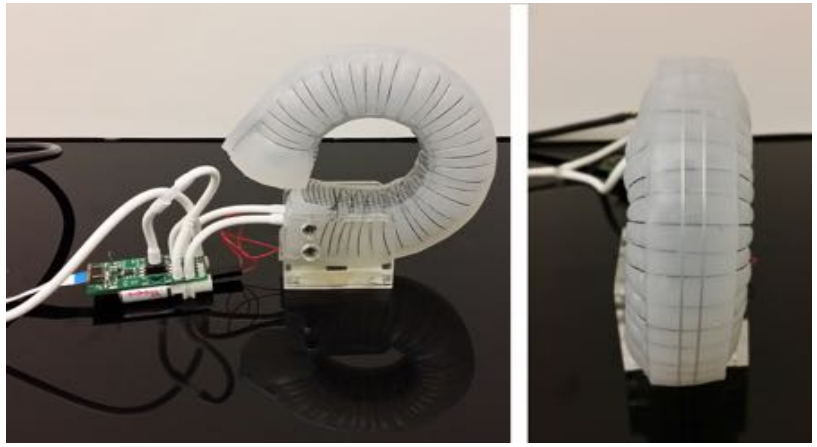
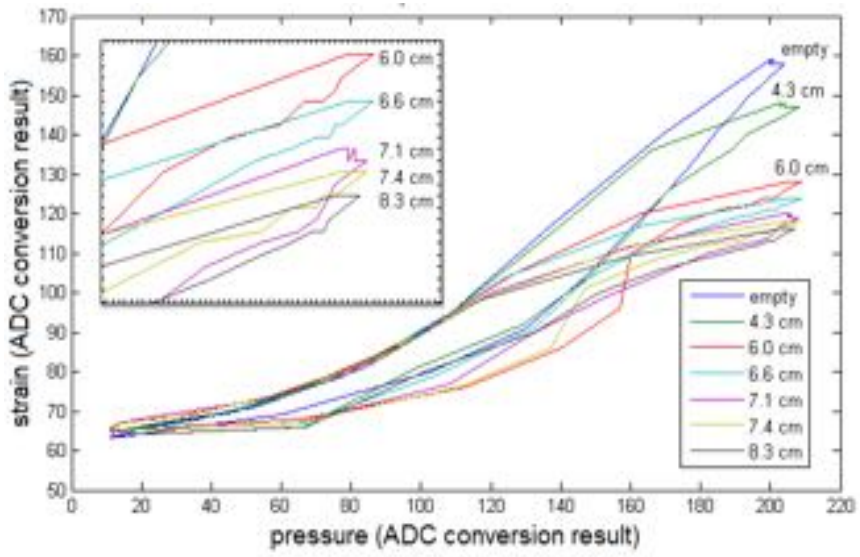
Example III: Manipulation





N. Farrow, N. Correll (2015): A Self-Contained Soft Pneumatic Actuator that can sense touch and grasp. Int. Conf. on Intelligent Robots and Systems (IROS).

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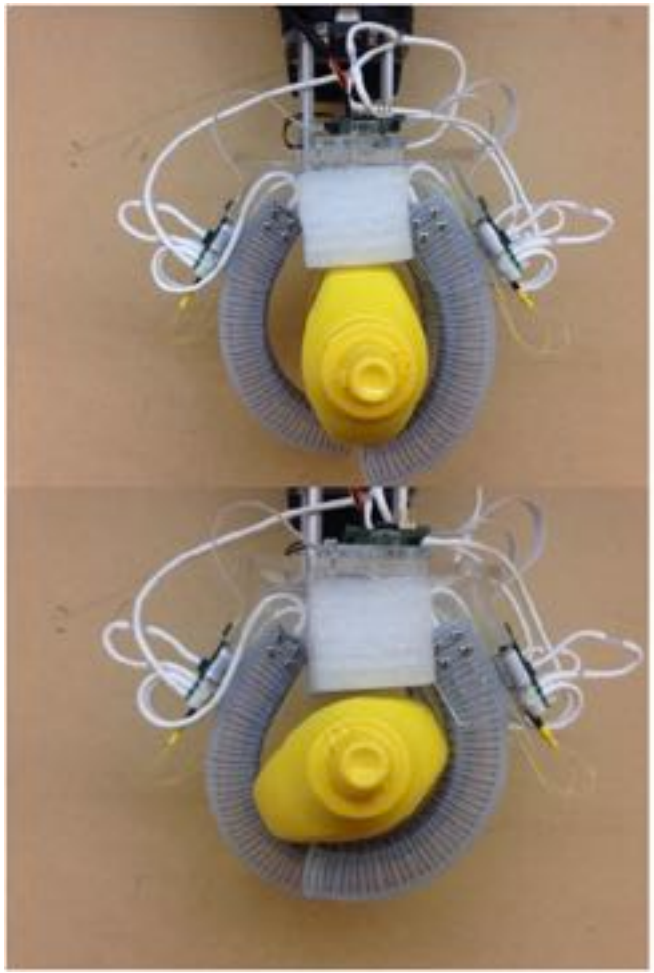
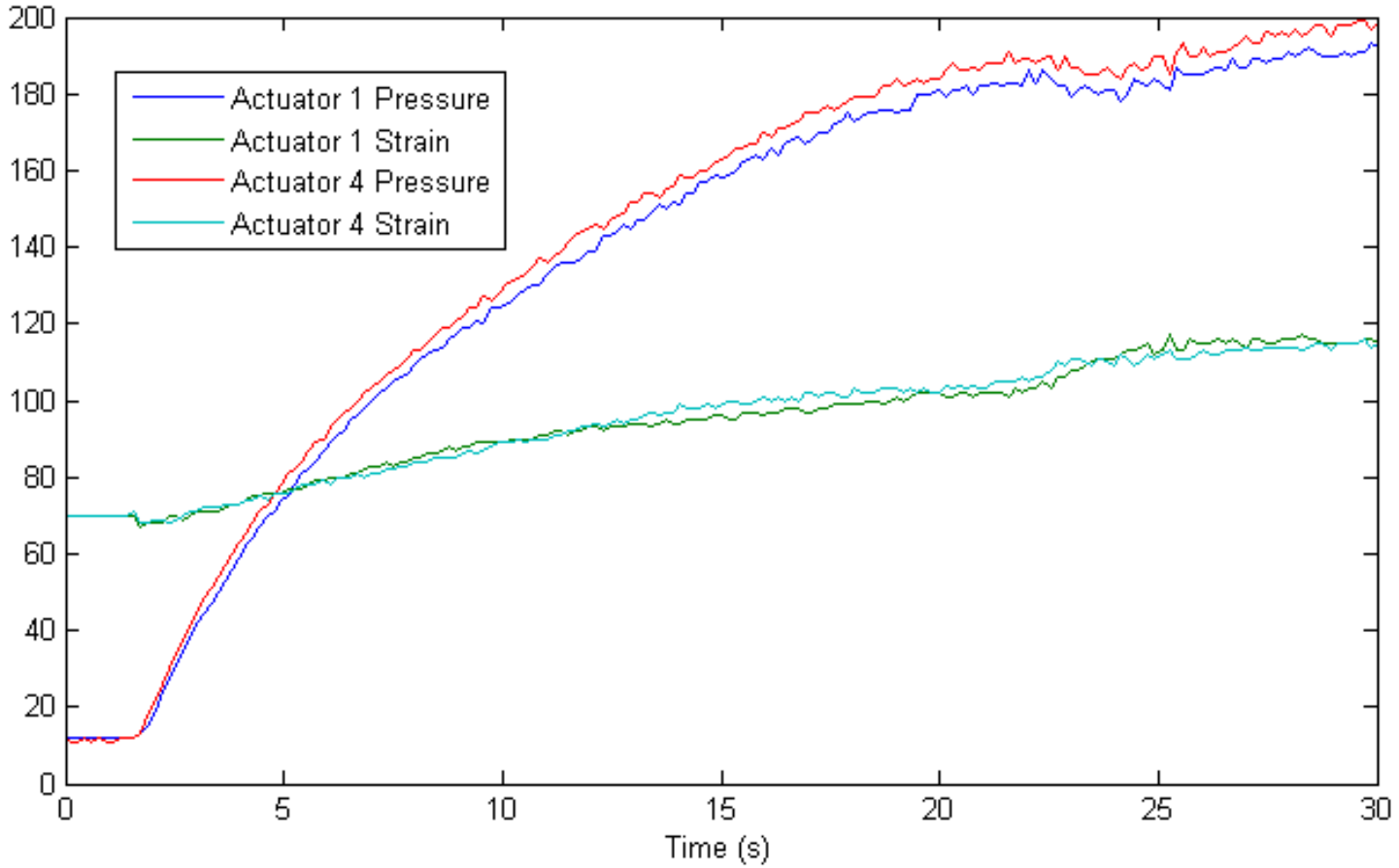
Active compliance

Initial grasp
(bad force closure)

After wiggling
(good force closure)

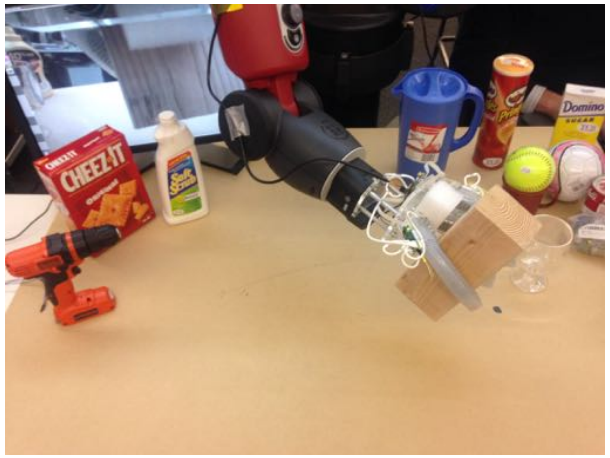




Nicholas Farrow, Yang Li and Nikolaus Correll. "Morphological and Embedded Computation in a A Self-contained Soft Robotic Hand". arXiv:1605.00354

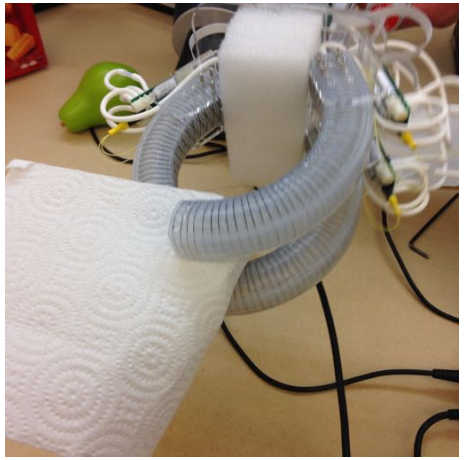
Challenging grasps

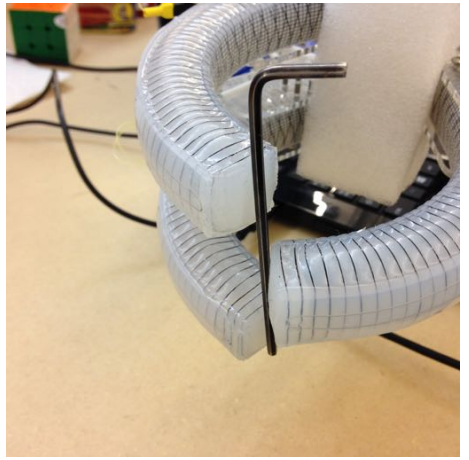
Power grasps (easy)



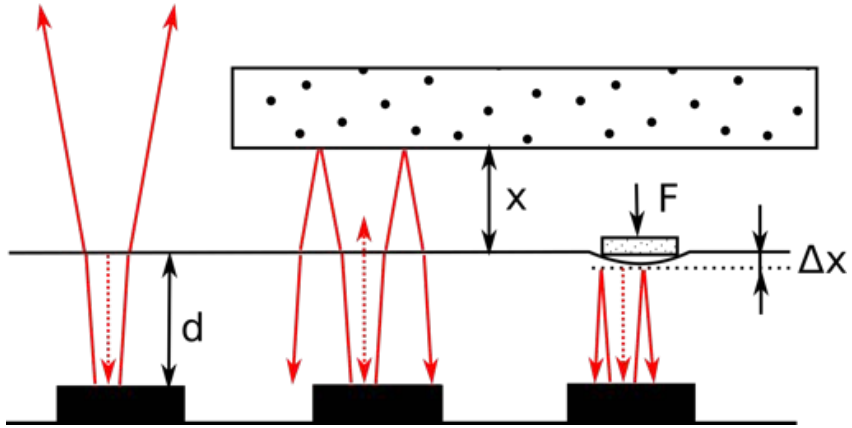
medium

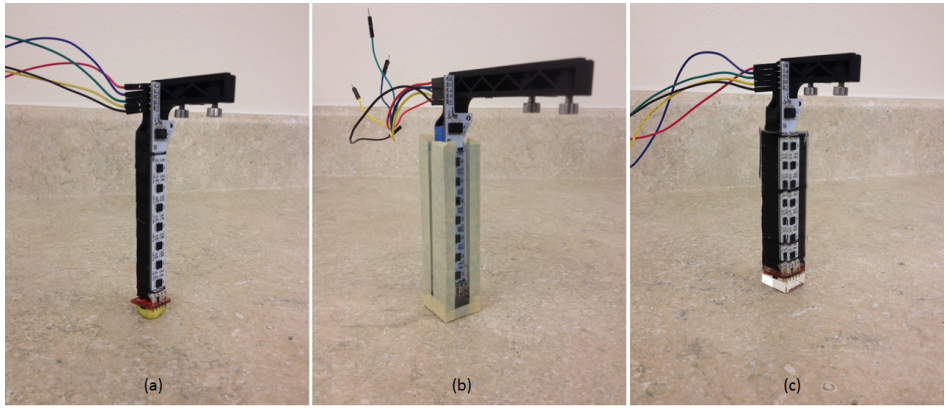
Pinching grasps (hard)

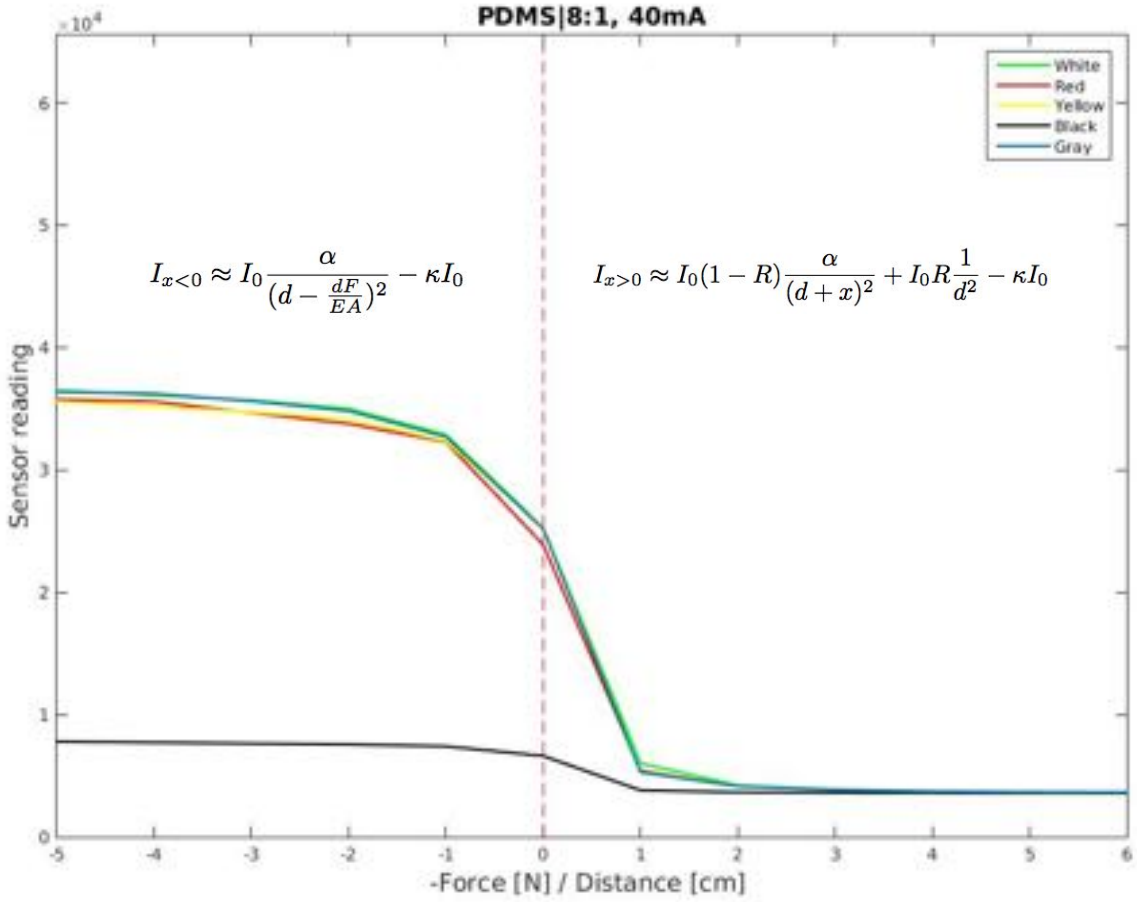




Combined distance and force sensing



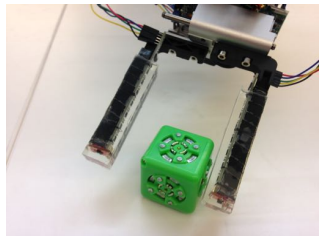




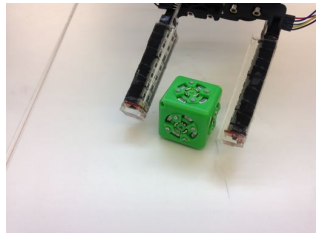
R. Patel and N. Correll. Integrated force and distance sensing for robotic manipulation using elastomer-embedded commodity proximity sensors. ``Robotics: Science and Systems'' (RSS), 2016.

Tactile and distance sensing during grasping

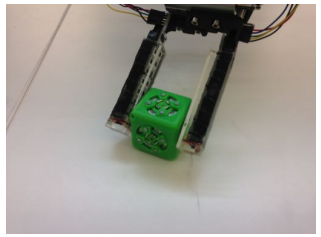
1. Approach



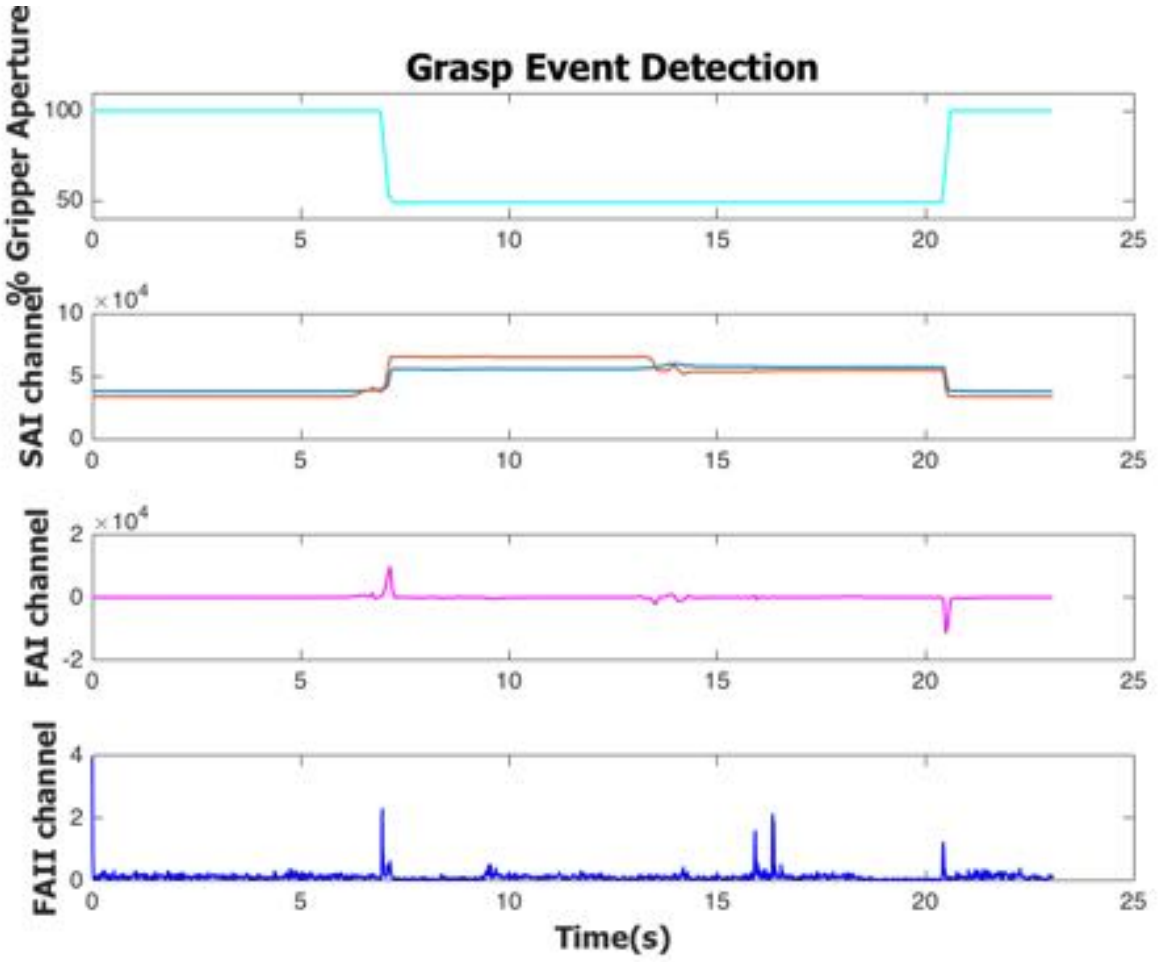
2. Align



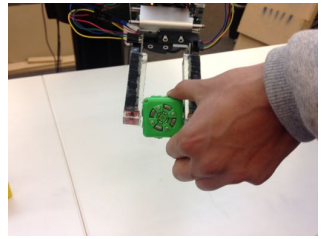
3. Contact



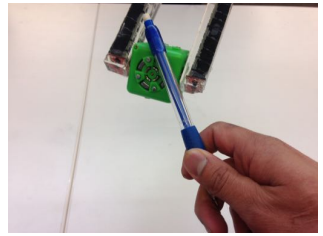
4. Loading



5. Disturbance (wrench)



6. Disturbance (tapping)

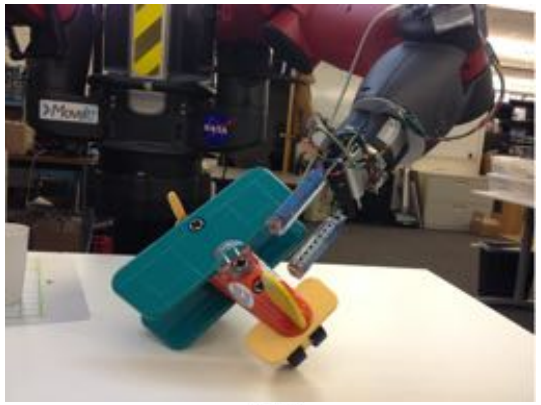


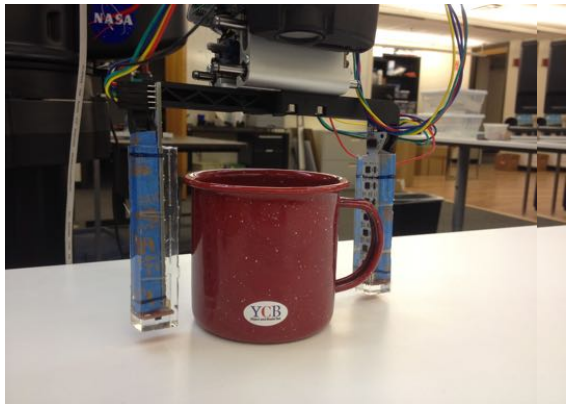
7. Replacement

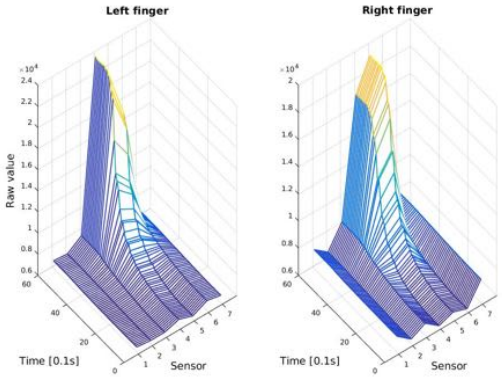
8. Release

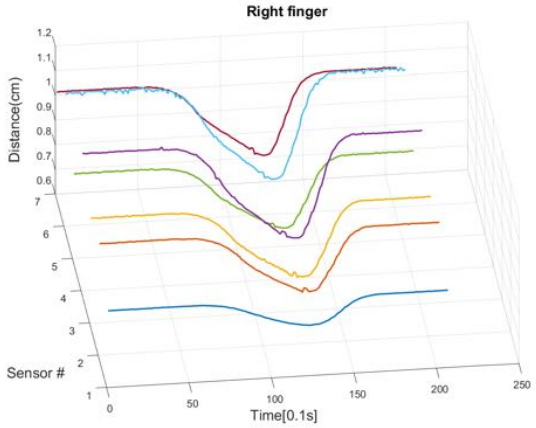
R. Patel and N. Correll. Improving grasp performance using in-hand proximity and force sensing. Int. Symposium on Experimental Robotics (ISER), 2016.

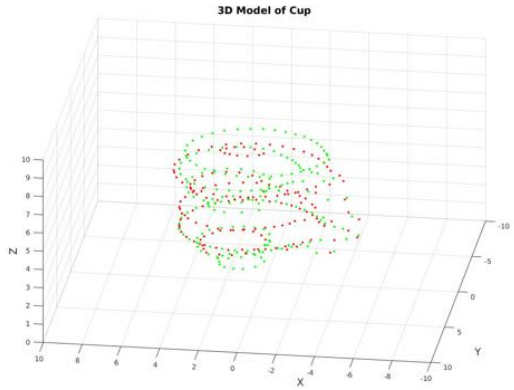
Contact sensing and 3D scanning







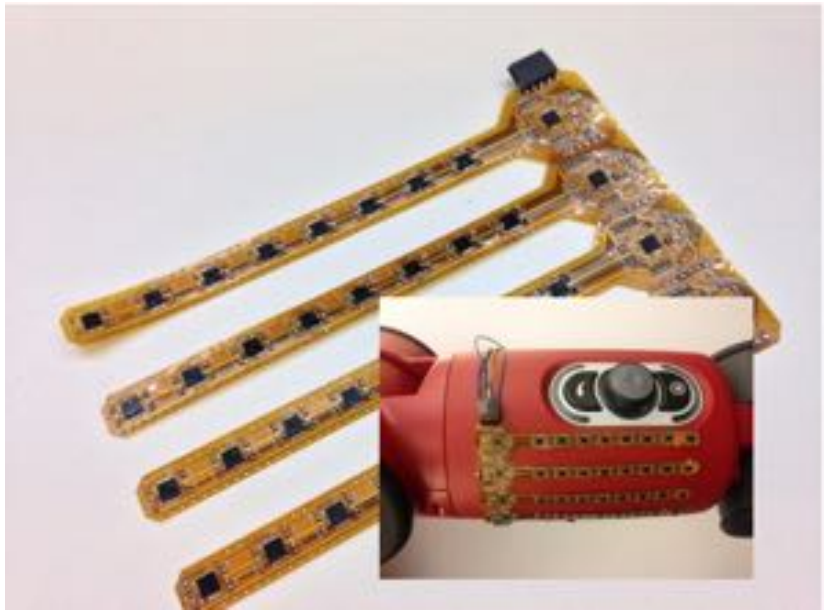


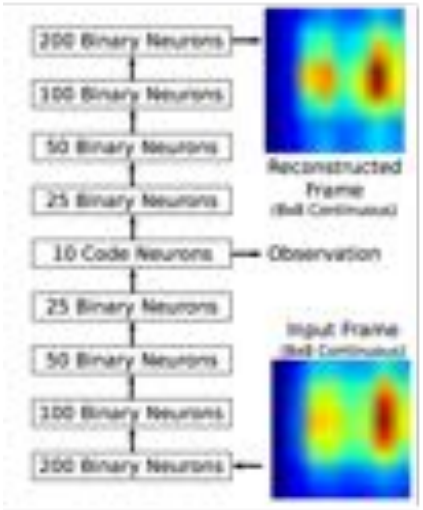


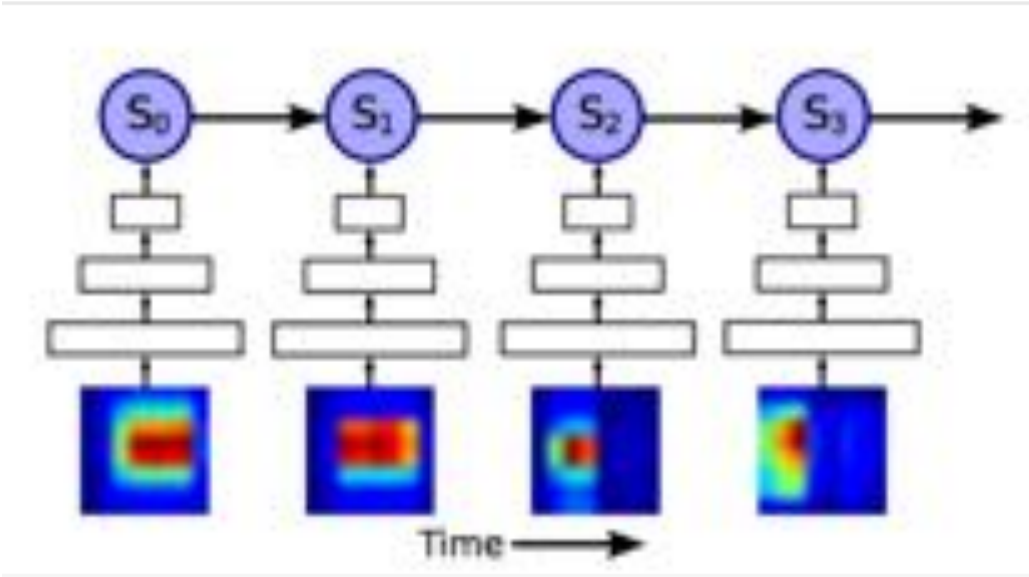
Contact sensing

3D scanning

Whole-body sensing: social touch and collision avoidance



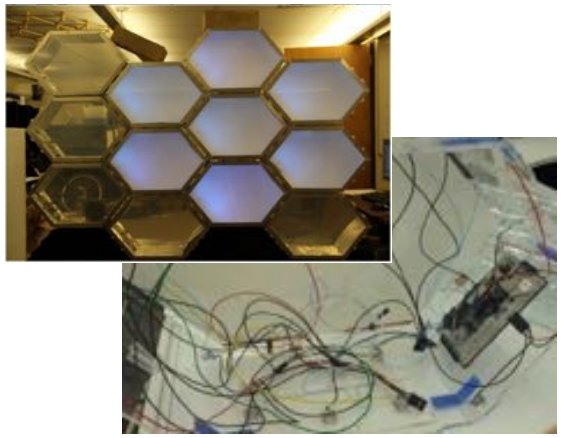


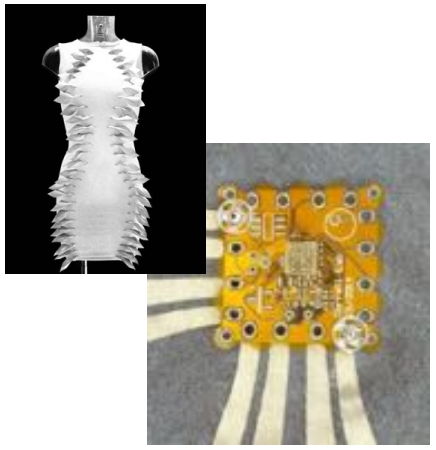


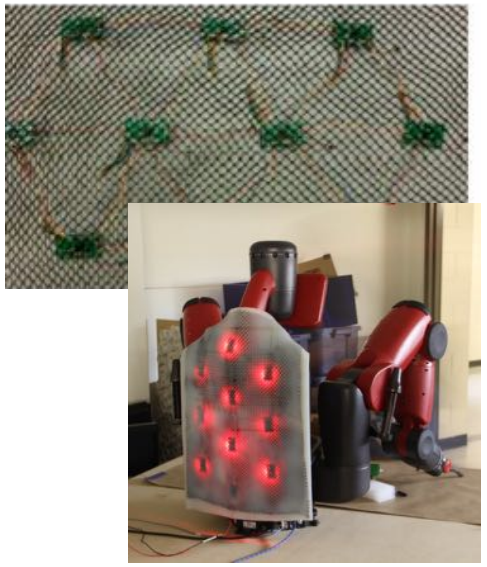
Actual Labels	Classified Label													
	a	b	c	d	e	f	g	h	i	j	k	l	m	n
grab (a)	**83**	1	4	0	4	0	13	1	0	0	74	0	0	0
hit (b)	0	**61**	0	19	0	19	0	0	0	36	0	1	19	0
massage (c)	6	0	**77**	0	1	0	0	7	10	0	7	0	0	10
pat (d)	0	7	0	**45**	1	1	1	0	2	4	0	3	29	2
pinch (e)	0	1	2	1	**67**	4	3	0	1	1	5	3	1	5
poke (f)	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**

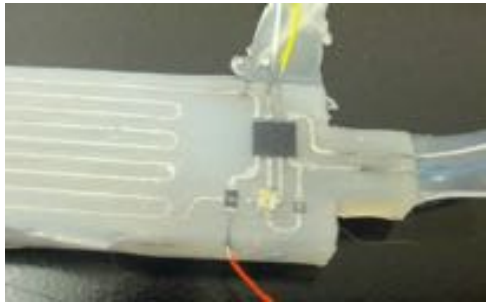
D. Hughes, N. Farrow, H. Profita, N. Correll (2015): Detecting and Identifying Tactile Gestures using Deep Autoencoders, Geometric Moments and Gesture Level Features. ACM International Conference on Multimodal Interaction, Recognition of Social Touch Gestures Challenge, Seattle,

Key Challenge: Manufacturing Robotic materials economically









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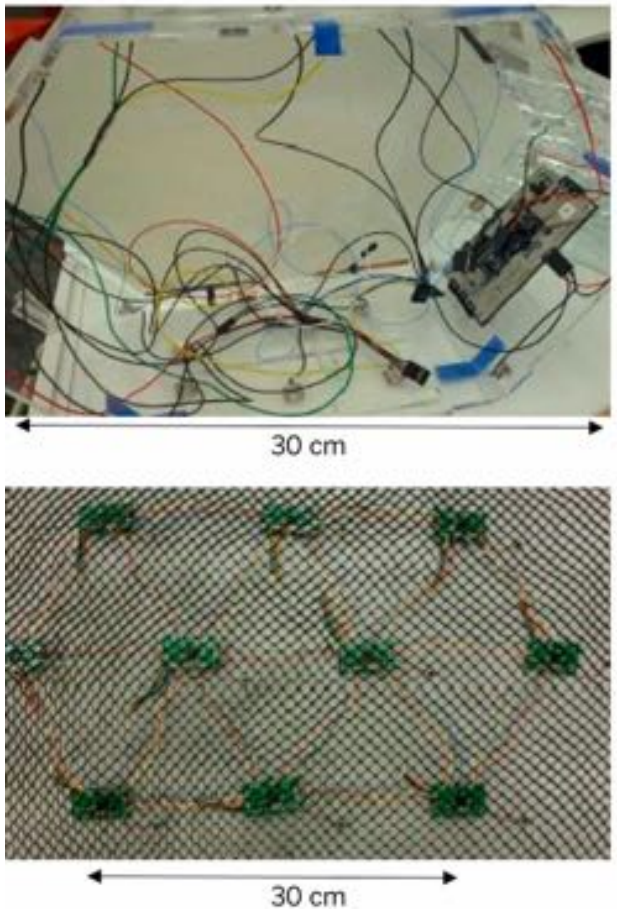
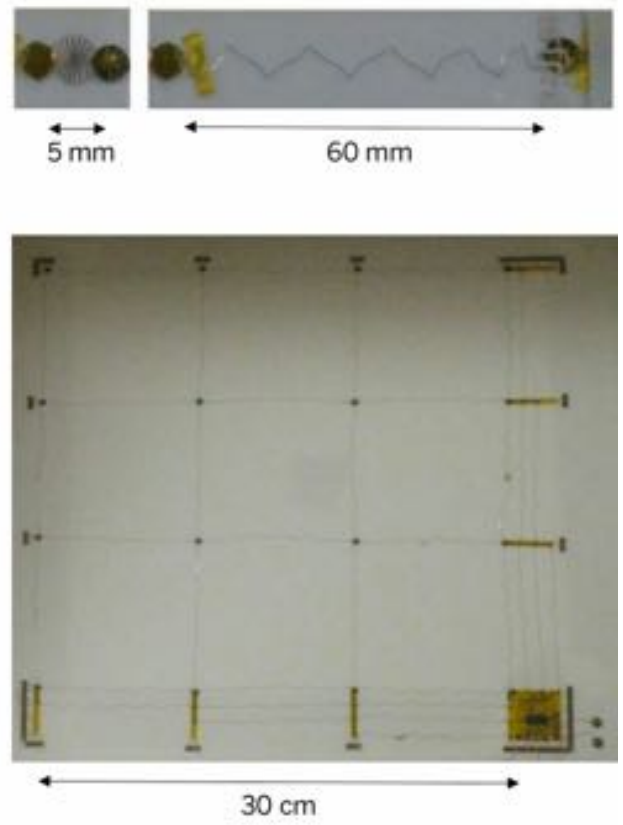
1. Novel manufacturing techniques: stretchable CMOS

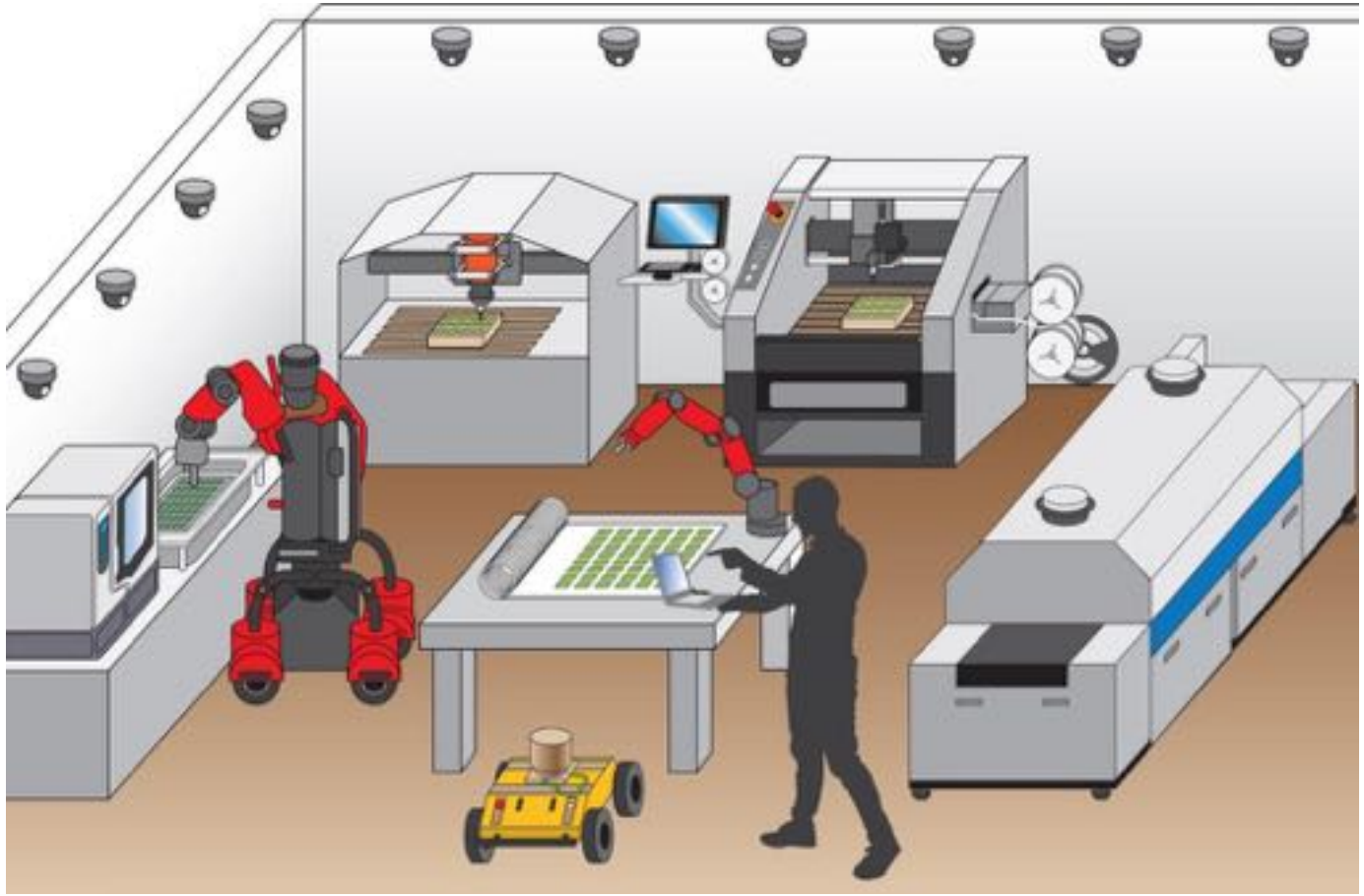




Fu-Kuo Chang, Stanford

2. Increasing manufacturing efficiency

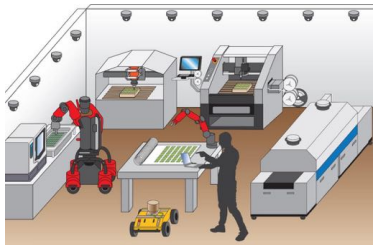
- Use robots for precise placement of components and interconnects
- Use robots to provide the “glue” between different manufacturing steps



Conclusion

- Robotics needs to go beyond gears, links and belts
- Mimic tight integration of sensing, actuation, computation and communication of biological systems
- Improve robot autonomy
- **Create a new class of composite materials with built-in intelligence**
- Stay tuned:

  Stefan Bosse, Manuel Collet, Dirk Lehmhus, Walter Lang, and Matthias Busse: Material-integrated Intelligent Systems. Sensorial Materials, Adaptive Metacomposites and the fundamentals of realizing material-integrated intelligence. Wiley VCH, forthcoming.



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Acknowledgements