Inferring hand-object configuration directly from tactile data

Robert Platt
MIT

Frank Permenter
Oceaneering Space Systems

Joel Pfeiffer
Purdue University

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Problem

Track "haptic features" in a flexible material by touch

- Buttons/grommets sewn into cloth
- Divots in flexible plastic

Today, I focus on the localization problem only…

Tools: compliance and tactile sensing

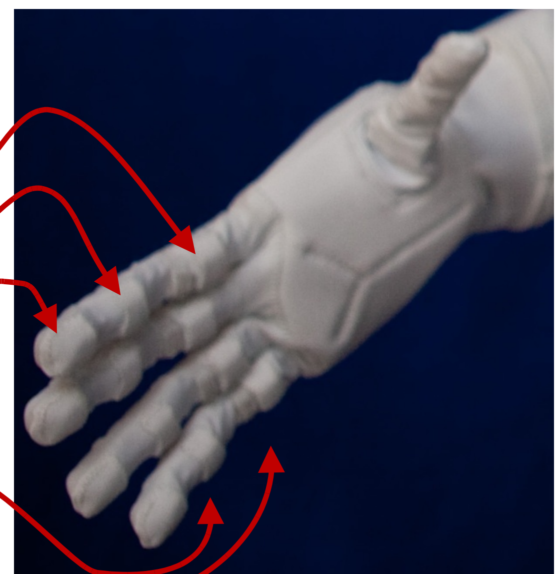
Yesterday's talk:

- Used compliance and tactile sensing to localize an inflexible object

Robonaut 2:

Six-axis load cells

Actively compliant finger joints



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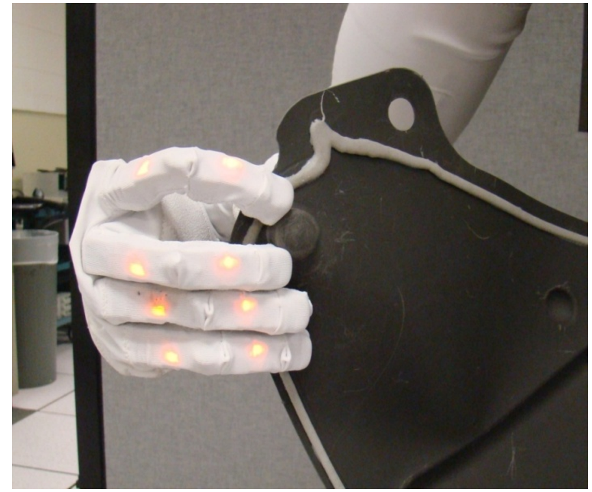
Mode of interaction

1. Hold material between thumb and forefingers
2. Squeeze and pull such that fingers slide over material



As a consequence of mode of interaction:

1. State space: 2-d coordinates on flexible material
2. Always pulling in one direction means that we can eliminate velocity component of state

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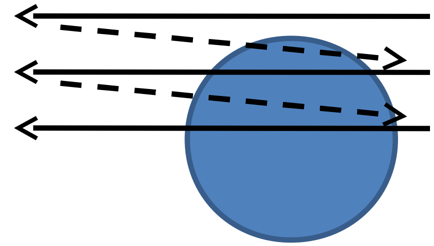
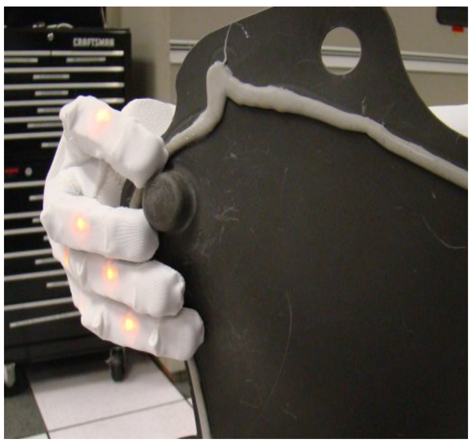
Sensor model

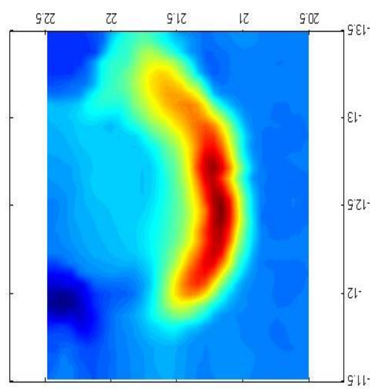
Goal: model expected sensor measurements as a function of hand-feature state.



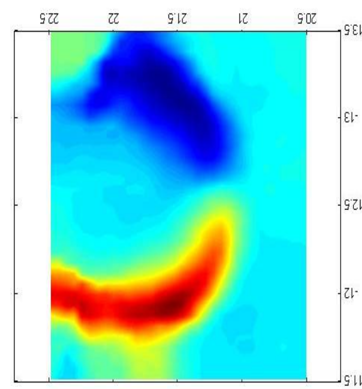
- Training phase where multiple “swipes” are performed.
- Measurements: 8 signals per phalange



Signal 1



Signal 2



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“Haptic Map”: mean signal as a function of 2-d state:

$$\hat{z}(x) = \frac{1}{k} \sum_{z \in N_k(x)} z$$

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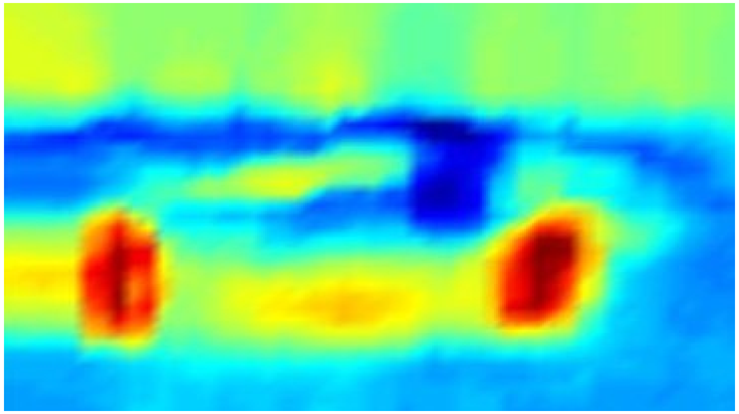
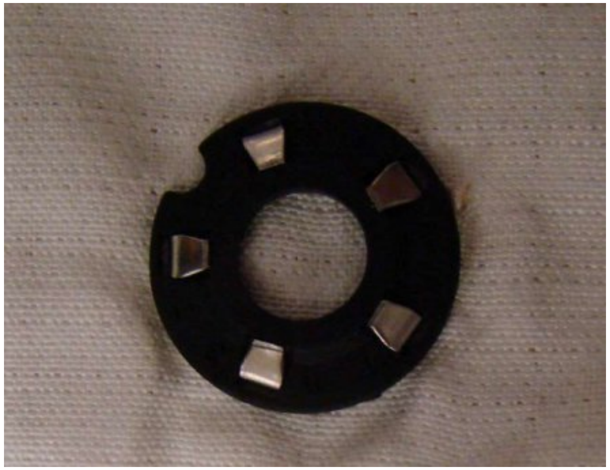
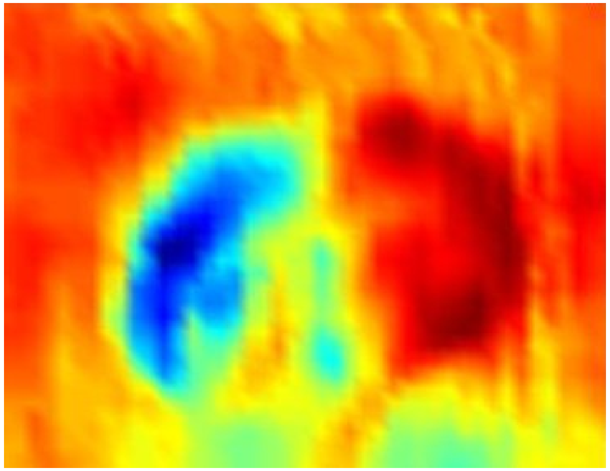
More haptic maps

Grommet

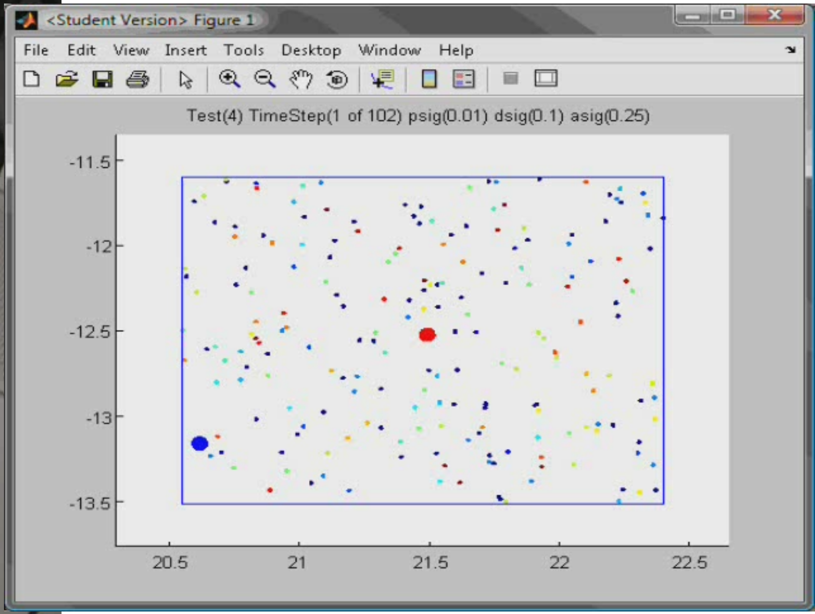


Snap





Application of particle filter



Measurement model: Gaussian over measurements fit to nearest neighbors in state space:

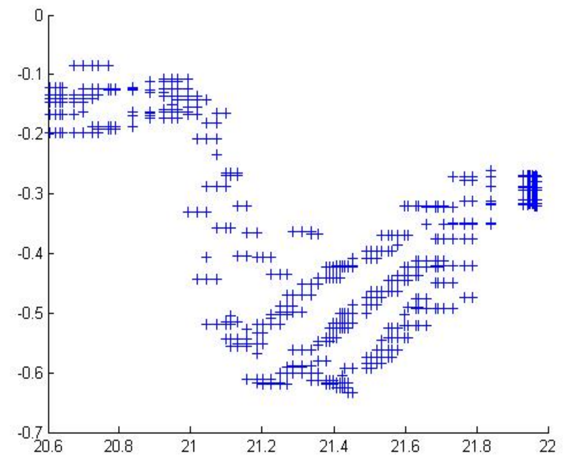
$$P(z \mid x) = N\left(z \mid \hat{z}(x), \Sigma(x)\right)$$

Mean and covariance calculated over k nearest neighbors

$$\hat{z}(x) = \frac{1}{k} \sum_{z \in N_k(x)} z$$

Different models

Gaussian model: $P(z \mid x) = N(z \mid \hat{z}(x), \Sigma(x))$



Independent fingers: $\Sigma(x) = \begin{bmatrix} \Sigma_1(x) & 0 \\ 0 & \Sigma_2(x) \end{bmatrix}$

Mixture of Gaussians: $P(z_i \mid x_i) = \sum_{(x,z)\in D} N\left(\begin{matrix} x_i \\ z_i \end{matrix} \middle| \begin{matrix} x \\ z \end{matrix}, \begin{pmatrix} \Sigma_x & 0 \\ 0 & \Sigma_z \end{pmatrix} \right)$

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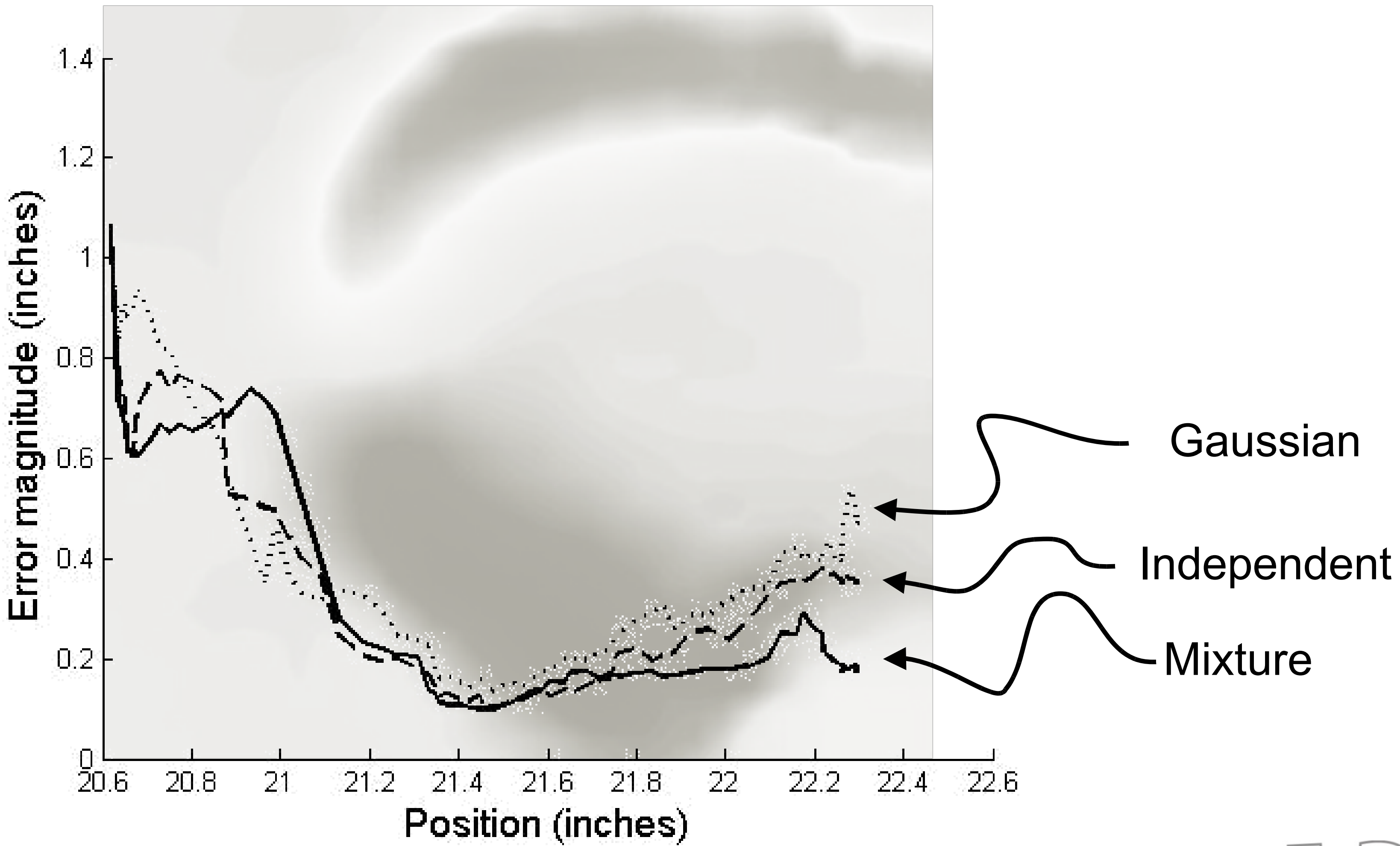
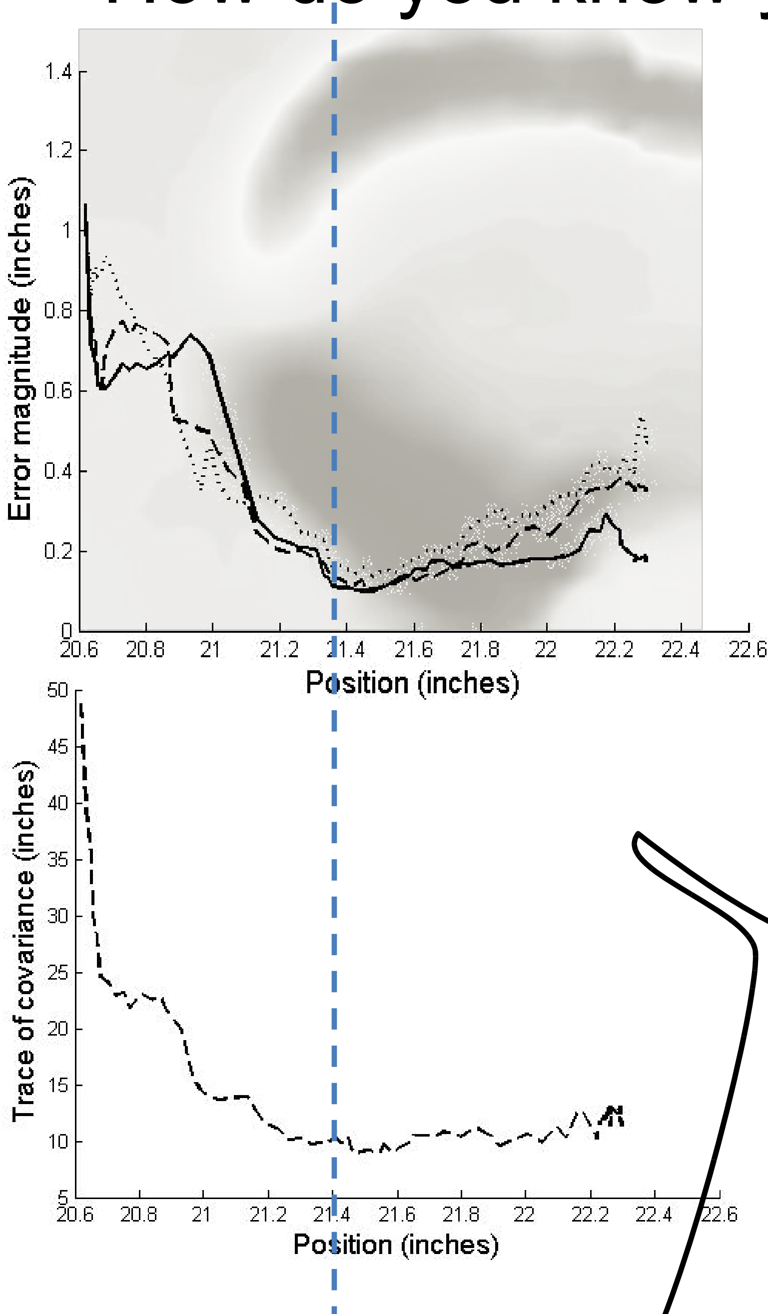
Performance



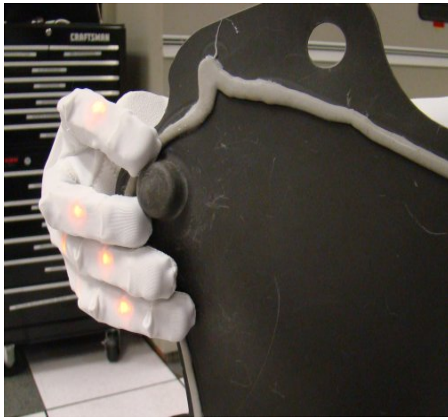
How do you know you got it right?



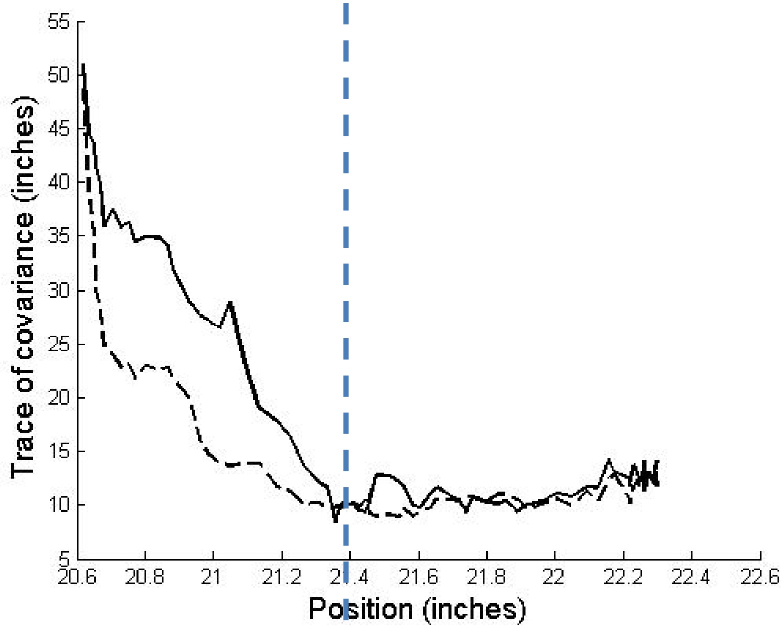
How do you know that you're not here?

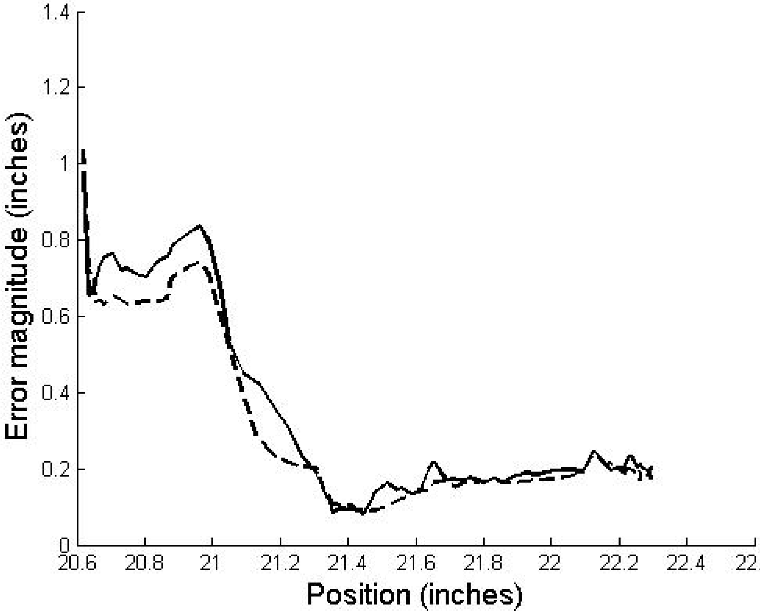
Reduce overfitting via on-off bump model

1. Factor likelihood by phalange: $P(z \mid x) = \prod_k P(z^k \mid x)$



2. Enforce a uniform distribution over "off bump" region:





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Grommet application

Fabric pivots freely

Contributions

1. Accurate localization (0.1 inch) of features in fabric for the first time.

2. Propose a mode of interaction that simplifies the dimensionality of state estimation problem

3. Propose relevant measurement models

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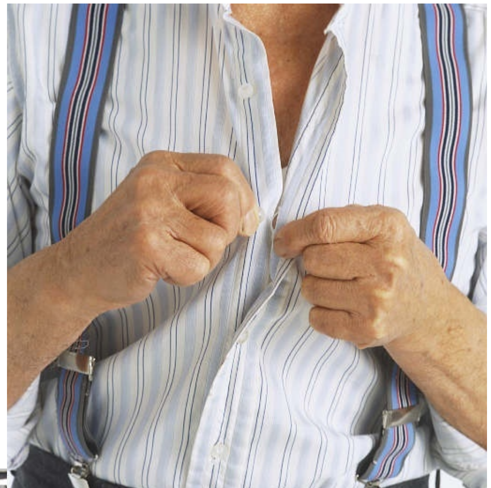
Problem



Track "haptic features" in a flexible material

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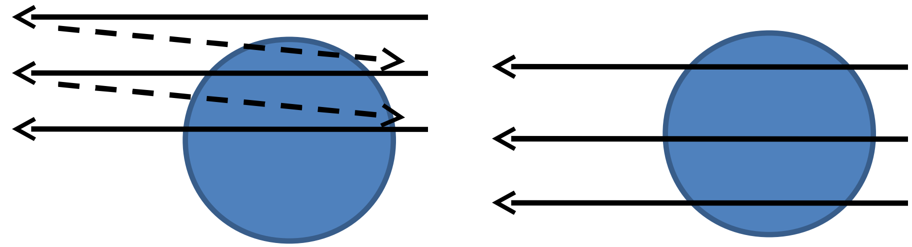
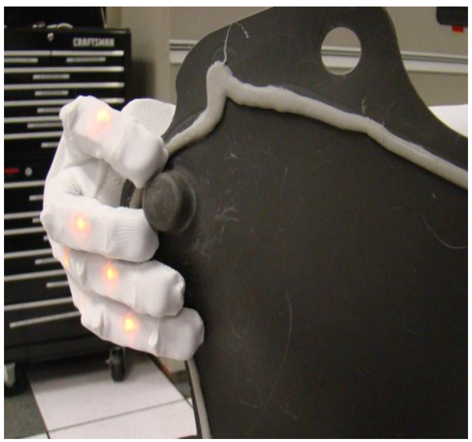
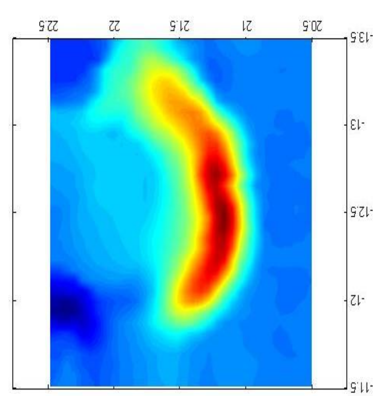
Measurement model: the “haptic map”

Training swipes:

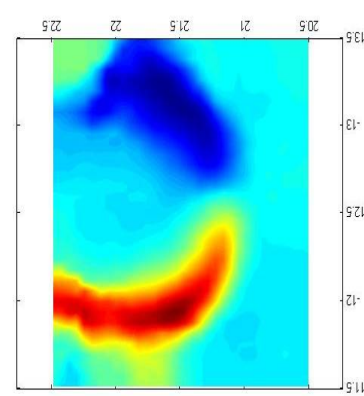




Signal 1



Signal 2



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$$P(z \mid x) = N\left(z \mid \hat{z}(x), \Sigma(x)\right) \qquad \hat{z}(x) = \frac{1}{k} \sum_{z \in N_k(x)} z$$

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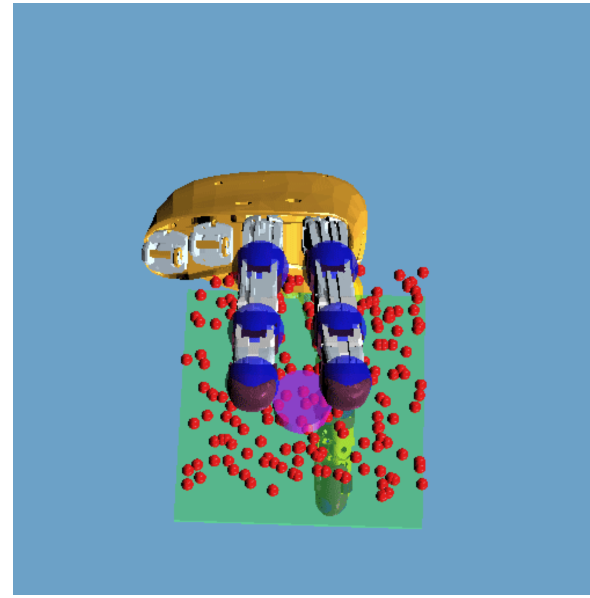
Approach: particle filter

1. Training phase: model relation between finger positions and sensor data
2. Test phase: estimate state based on sensor data



Gaussian measurement model:

$$P(z \mid x) = N\left(z \mid \hat{z}(x), \Sigma(x)\right)$$

Mean and covariance calculated over *k* nearest neighbors

High-DOF sensor measurements

2-DOF state

Platt, R., Permenter, F., Pfeiffer, J., (Workshop on manipulation, ICRA 2010)

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