Tactile Sensing: Steps to Artificial Somatosensory Maps

G. Cannata, S. Denei, F. Mastrogiavovanni

University of Genova

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Scenario

Skin based robot tasks

Skin based application software (incl. basic robot behaviors)

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Outline

- Context & Motivations
- How to build a somatosensory map?
  - Skin Self-Calibration
  - 2D Mapping
- Simple results
- Possible applications
Context & Motivations

- Full-body tactile representation depends on:
  - robot morphology and shape
  - taxels placement (and density) over the robot surface

- **Goal**: Investigate robot-independent representation structures for high-level behaviors:
  - touch classification
  - robot control
  - “body awareness”
Context & Motivations
Somatosensory maps preserve the topographic arrangement between tactile elements in 2D:
- Distortions are allowed but should be minimized
- An “atlas” can be created

Somatosensory maps can describe more abstract contact features:
- Contacts over large areas can be represented using single units (i.e., “left forearm in contact”)
- Hierarchical data structures are possible
Steps:

1. **Skin Calibration**: a triangulated 3D mesh representing robot skin at the surface is obtained.
2. **2D Mapping**: the mesh is parameterized in order to preserve taxel topographic arrangement (i.e., areas, angles or their combination).
**Step #1: Skin Self–Calibration**

**Definition:**
The automated process of estimating the location (and in the future also the response) of each taxel with respect to a robot-centered reference frame, after the “skin” has been actually fixed on a robot body part.

Raw data $p = p(x, y, z, t)$ $p \in \mathbb{R}^k$

**Step #1: Skin Self-Calibration**

**Idea:**
To produce the required tactile stimuli by assigning the robot with a motion control law able to guarantee contact with an external object, which position is known, thereby activating taxels in a “controlled” way.
Skin–Calibration Results

A mesh–like data structure:
- Each vertex represents a taxel pose in 3D
- Still dependent on robot morphology
- Still difficult to operate upon
Idea:

- Exploiting very old ideas from Minimal Surface Theory
- Obtaining a generic 2D representation of 3D skin meshes preserving regularity and topographic properties of the skin geometry
Given a discrete 3D surface $S$ (i.e., calibrated skin, possibly with holes), the goal is to build a piecewise linear mapping $\Psi : S \rightarrow M$ between $S$ and an isomorphic discrete 2D surface $M$ (i.e., a cognitive map made up of $s$ triangles $T_{M,1}, \ldots, T_{M,s}$) best preserving the intrinsic properties of $S$. 
The initial problem can be reformulated as determining an isomorphic discrete 2D surface $\mathcal{M}$ such that a properly defined energy functional $E(S, \mathcal{M})$ is minimal.

$$M = \arg \min_{\mathcal{M} \sim S} E(S, \mathcal{M}),$$

$$\frac{\partial E}{\partial m_i} = 0.$$
Step #2: 2D Mapping

\[ E = \lambda_1 E^a + \lambda_2 E^\chi \]

\[ E^a = \sum_{(j,i) \in \Delta_r} \cot \alpha_{ij} |m_i - m_j|^2. \]

\[ E^\chi = \sum_{j:(j,i) \in \Delta_r} \frac{\cot \alpha_{ij} + \cot \beta_{ij}}{|t_i - t_j|^2} (m_i - m_j)^2. \]

\[ \frac{\partial E^a}{\partial m_i} = \sum_{j:(j,i) \in \Delta_r} (\cot \alpha_{ij} + \cot \beta_{ij}) (m_i - m_j) = 0, \]

\[ \frac{\partial E^\chi}{\partial m_i} = \sum_{j:(j,i) \in \Delta_r} \frac{\cot \alpha_{ij} + \cot \beta_{ij}}{|t_i - t_j|^2} (m_i - m_j) = 0. \]

Intrinsic Parameterization

Angle Preserving

Area Preserving
2D Mapping Results

2D data structure
How can we exploit this data structure for designing high-level behaviors?

- Tactile-based control strategies
- Touch classification by means of nonlinear oscillators
- Hierarchical representation using a tactile “atlas”
Tactile-based Control Strategies
Touch Classification
Touch Classification
Building a Skin Atlas

Artificial Dermatomes?
Summary

- A process to build a skin representation independent from robot morphology
- Data structures to ground high-level data processing and control behaviors
- Next: assessment of contact models and their integration with the data structures
- Next: Skin calibration by means of self-touch & with a real robot