Challenges in Cloth Manipulation by Robots

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Outline

1. Our standpoint

2. From industrial to assistive robotics: Research challenges

3. CLOTHILDE project: Computational Topology and Motion Learning

4. Social implications and Ethics education
Our standpoint

Affiliation: Institut de Robòtica i Informàtica Industrial

- 36 Doctors
- 45 PhD students
- 10 Technicians
- 14 Support staff
- >10 Robots
Our standpoint

Affiliation: Institut de Robòtica i Informàtica Industrial

Group/Laboratory: Robot Perception and Manipulation
Our standpoint

Affiliation: Institut de Robòtica i Informàtica Industrial

Group/Laboratory: Robot Perception and Manipulation

Target domain: Assistive and Collaborative Robotics - Clothing
Our standpoint

Affiliation: Institut de Robòtica i Informàtica Industrial

Group/Laboratory: Robot Perception and Manipulation

Permanent: 6
Postdocs: 8
Predocs: 10
Technicians: 2

Master: 4
TFG: 4
Our standpoint

Affiliation: Institut de Robòtica i Informàtica Industrial

Group/Laboratory: Robot Perception and Manipulation

Target domain: Assistive and Collaborative Robotics - Clothing Research at the frontier between Robotics and AI
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Research challenges

Industrial robots → Assistive robots

- Programmed by experts
- Caged
- Rigid objects
- Accurate
- Fixed sequences
- Non-interactive

- Easy to instruct by non-experts
- Intrinsically safe for people
- Able to perceive and manipulate non-rigid objects
- Tolerant to noisy perceptions and inaccurate actions
- Capable of goal-directed execution
- Collaborating with people
Usability + Safety
Easy instruction by non-experts + compliant execution

Exhaustive **programming** taking into account all situations
+ robot **caged**

Learning from **demonstrations**
+ control based on a model of **robot dynamics**
Usability + Safety
Easy instruction by non-experts + guaranteed safe execution
Perception and manipulation of non-rigid objects
Handling uncertainty in perceptions and actions

High-resolution perception + Accurate manipulation planning

Task-oriented perception + Probabilistic planning

Both call for Machine Learning techniques
Perception and manipulation of non-rigid objects
Handling uncertainty in perceptions and actions

RGB-D descriptor
+ Bag-of-words
+ SVM

ICRA'12
EAAI, 2014
IROS'13
PR, 2016
Collaborating with people + Customizable
Communicating to users + adaptivity

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CLOTHILDE

CLOTH manipulation Learning from DEMonstrations

Application domains:

- Housekeeping and hospital logistics
- Automation in the clothing and internet business
- Increasing the autonomy of the elderly and disabled
Theory of cloth manipulation based on computational topology

Cloth Perception | Manipulation and Planning | Learning from Demonstration
CLOTHILDE
Theory of cloth manipulation based on computational topology

Cell complexes

Persistent homology
Configuration spaces

Direct kinematics of serial manipulators

Given joint angles...

... find the position and orientation of end-effector.

$$\mathbb{R}^3 \times SO_3(\mathbb{R}) \leftarrow \mathbb{R}^6$$

(1) \hspace{1cm} (n)
Configuration spaces

Inverse kinematics of serial manipulators

Given the position and orientation of end-effector...

... find the feasible sets of joint angles.

\[ \mathbb{R}^3 \times SO_3(\mathbb{R}) \leftrightarrow \mathbb{R}^6 \]

(1) (n)
Configuration spaces
Kinematics of parallel manipulators

Configuration space

6 joints
End-effector
Base

Platform
6 actuators
Base

\[ \mathbb{R}^3 \times SO_3(\mathbb{R}) \leftrightarrow \mathbb{R}^6 \]

(1) \hspace{1cm} (n)

\[ \mathbb{R}^3 \times SO_3(\mathbb{R}) \leftrightarrow \mathbb{R}^6 \]

(n) \hspace{1cm} (1)
Configuration space - Singularities

Parallel manipulators

- Contact point-plane
- Contact line-line
- Contact plane-point

Flag
Configuration space - Singularities

Flagged manipulators

flag
Flag manifold
Stratification - cell complex

The disjoint union of Bruhat cells: $B^w$:

\[
\text{Flag}(4) = \bigcup_{w \in \Sigma_4} B^w,
\]

with

$B^u \cap \overline{B^w} \neq \emptyset$ if and only if $B^u \subset \overline{B^w}$,

is a stratification of the flag manifold.
Flag manifold

6D and 5D cells
Cell complex

6D and 5D strata

Projective flags

Affine flags

\[ B^{(4,3,2,1)} \]

\[ B^{(4,2,3,1)} \]

\[ l \cdot l^* \]

\[ B^{(4,3,2,1)}_+ \]

\[ (v - p^*)^+ \]

\[ (p - v^*)^+ \]

\[ (l \cdot l^*)^+ \]

\[ B^{(4,3,2,1)}_- \]

\[ (v - p^*)^- \]

\[ (p - v^*)^- \]

\[ (l \cdot l^*)^- \]

\[ p - v^* \]

\[ v - p^* \]

\[ x 2 \]

\[ x 4 \]
Flags invariant to some transformations

Abelian group $C_2 \times C_2$
Cell complex

6D and 5D strata

Projective flags

Affine flags

\[ B^{(4,3,1,2)}_{v - p^*} \]

\[ B^{(4,3,2,1)}_{p - v^*} \]

\[ B^{(4,2,3,1)}_{l \cdot l^*} \]

\[ (v - p^*)^+ \]

\[ B^{(4,3,2,1)}_+ \]

\[ (l \cdot l^*)^+ \]

\[ (p - v^*)^+ \]

\[ (p - v^*)^- \]

\[ B^{(4,3,2,1)}_- \]

\[ (v - p^*)^- \]

\[ (l \cdot l^*)^- \]
Cell complex

6D and 5D strata

Configuration space of flagged parallel robot

\( \times 4 \)

Math and physics of cloth manipulation

Work in progress

- Topology and metrics of (infinite-dimensional) configuration space
- Mechanics of inextensible surfaces, including friction and collisions
Math and physics of cloth manipulation

Work in progress

• Topology and metrics of (infinite-dimensional) configuration space
• Mechanics of inextensible surfaces, including friction and collisions
• Numerical integration: FEM, keeping inextensibility (no oscillations! dullest possible simulation)
Cloth recognition and pose estimation
Work in progress

- Persistent homology: detection of gaps and boundaries
Cloth recognition and pose estimation

Work in progress

- Persistent homology: detection of gaps and boundaries
- Surface reconstruction: tight triangulation, rulings
Cloth recognition and pose estimation

Work in progress

- Persistent homology: detection of gaps and boundaries
- Surface reconstruction: tight triangulation, rulings
- Determining the pose of a clothing item (with hidden areas in an image) by combining deep learning with structural-topological constraints

From RGB

Predict the pose of the 3D mesh
CLOTHILDE

CLOTH manipulation Learning from DEMonstrations

Theory of cloth manipulation based on computational topology

Cloth Perception  Manipulation and Planning  Learning from Demonstration
Recognition of clothing items

(a) Shirt  
(b) Trousers

(c) Towel  
(d) Polo

![Single view confusion matrix](image)

<table>
<thead>
<tr>
<th>Approach</th>
<th>Number of garments</th>
<th>Accuracy %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al. [10]</td>
<td>3</td>
<td>81.67</td>
</tr>
<tr>
<td>Mariolis et al. [19]</td>
<td>3</td>
<td>89.38</td>
</tr>
<tr>
<td>Gabas et al. [20]</td>
<td>4</td>
<td>92</td>
</tr>
<tr>
<td>Our approach using only real images</td>
<td>4</td>
<td>88.61</td>
</tr>
<tr>
<td><strong>Our approach using synthetic and real images</strong></td>
<td>4</td>
<td><strong>96.85</strong></td>
</tr>
</tbody>
</table>
Bringing a garment to a reference pose


<table>
<thead>
<tr>
<th>Garment</th>
<th>Jeans</th>
<th>Jumper</th>
<th>T-Shirt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average error distance on the first grasping point</td>
<td>1.59</td>
<td>2.22</td>
<td>2.76</td>
</tr>
<tr>
<td>Average error distance on the second grasping point</td>
<td>1.52</td>
<td>1.18</td>
<td>2.16</td>
</tr>
</tbody>
</table>
Bringing a garment to a reference pose

Garment in a random pose. Grasping from first point...

Learning robot skills from demonstrations

Skill clustering through persistent homology

Robot skill samples

Encoding as DMPs

Dimensionality reduction

Persistent homology

Parameter vectors

Latent parameters

Number of robot skills

Learning robot skills from demonstrations
Skill clustering through persistent homology

Learning robot skills from demonstrations
Skill tuning through reinforcement learning

Dynamic Movement Primitives (DMP):

\[
\frac{\dot{z}}{\tau} = \alpha_z \left( \beta_z (g - y) - z \right) + F(x(t))
\]

\[
F(x(t)) = \theta^T g(t)
\]

\[
g_i(t) = \frac{\phi_i(x(t))}{\sum_j \phi_j(x(t))} x(t)
\]

Compact, rescalable, intuitive parametrization
Learning robot skills from demonstrations
Skill tuning through reinforcement learning

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Ethical and social implications

Assistive robots

Issues shared with other technologies:
- incidence on the job market
- legal liability
- privacy
- digital gap
- …

New issues in entering the domains of:
- decision making
- feelings & relationships
- human enhancement

Roboethics: subfield of applied ethics studying both the positive and negative implications of robotics for individuals and society.

1. Human ethics applied to robotics
2. Codes of ethics embedded in the robots themselves ("machine ethics")


- **euRobotics project** “The European Robotics Coordination Action”: deliverable D3.2.1- Ethical Legal and Societal issues in Robotics (2012)

2016-18: IEEE Standards Association opened a draft on Ethically Aligned Design to public discussion.
Roboethics
Education and dissemination

The ACM/IEEE Computer Science Curricula consists of 18 knowledge areas, one of which is: “Social Issues and Professional Practice” that includes courses related to Ethics in Technology.
Role of Science Fiction
Ethics education in Computer Science and Engineering

1. Anticipate possible future scenarios

“What SF stories can do better than almost anything else is to provide not just an idea for some specific technical innovation, but also to supply a coherent picture of that innovation being integrated into a society, into an economy, and into people’s lives.”

[Neal Stephenson, 2011]

2. Engage technology students

“Using fiction to teach ethics allows students to safely discuss and reason about difficult and emotionally charged issues without making the discussion personal.”

[Judy Goldsmith, 2018]
Modern Science Fiction related to Roboethics

“It is the relationships that we have constructed which in turn shape us”

Robert C. Solomon
“The Passions”
Modern Science Fiction related to Roboethics

https://mitpress.mit.edu/books/vestigial-heart
Modern Science Fiction related to Roboethics

Four items:

• A **novel** about a future society in which people rely on personal-assistant robots to navigate daily life.

• An **appendix** with 24 ethics questions raised by the novel, as well as hints to trigger a debate.

• An **online teacher's guide** for 6-8 sessions on "Ethics in Social Robotics and AI" following the chapters in the novel and including scholarly references for further reading.

• A **100-slide presentation** that teachers can use and extend as desired.

https://mitpress.mit.edu/books/vestigial-heart
Teaching materials

Ethics in Social Robotics

0. Overview and background
1. **Designing** the “perfect” assistant
2. Robot **appearance** and emotion
3. Robots in the **workplace**
4. Robots in **education**
5. Human-robot **interaction** and human dignity
6. Social **responsibility** and robot morality
7. Bibliography and initiatives to follow up
Amazing future perspectives

What role will the human and the robot play in this “pas à deux” in which we are irremissibly engaged?

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