



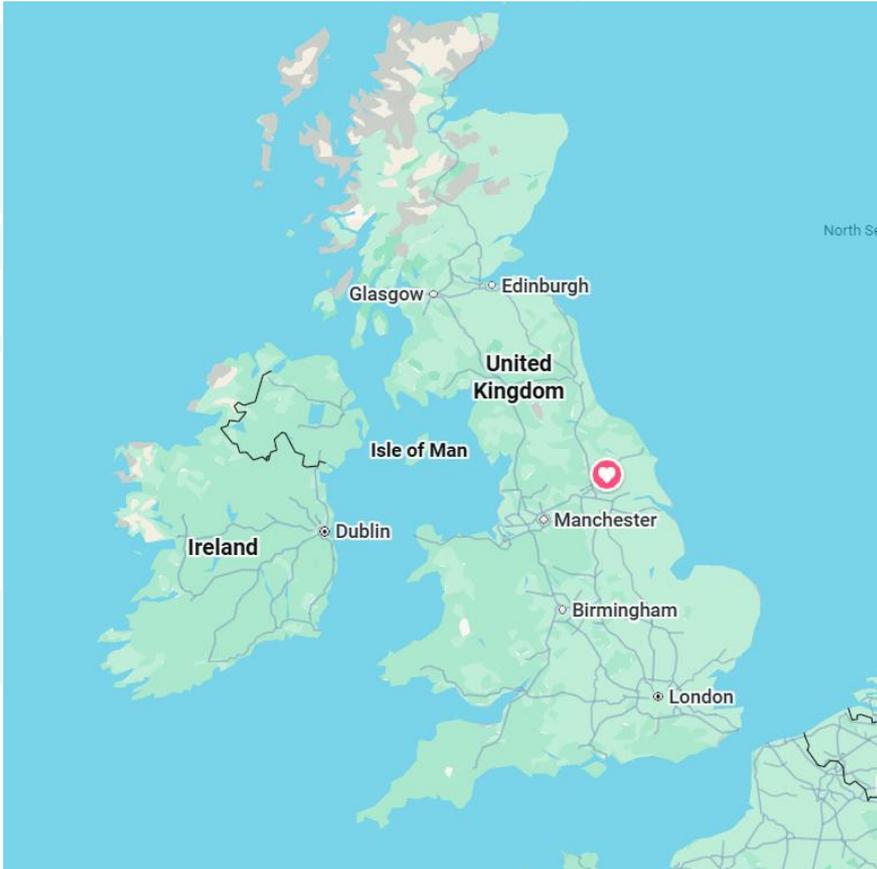
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Deformable Object Manipulation: fundamental challenges and promising applications

Talk at ROMANDIC Winter School
2026.02.12

Jihong Zhu
Assistant Professor of Robotics,
School of Physics, Engineering and Technology,
University of York







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We make robots **interact with complex objects/humans** with **control** and **machine learning**

Deformable object manipulation

Since 2017

Assistive robotics for caregiving

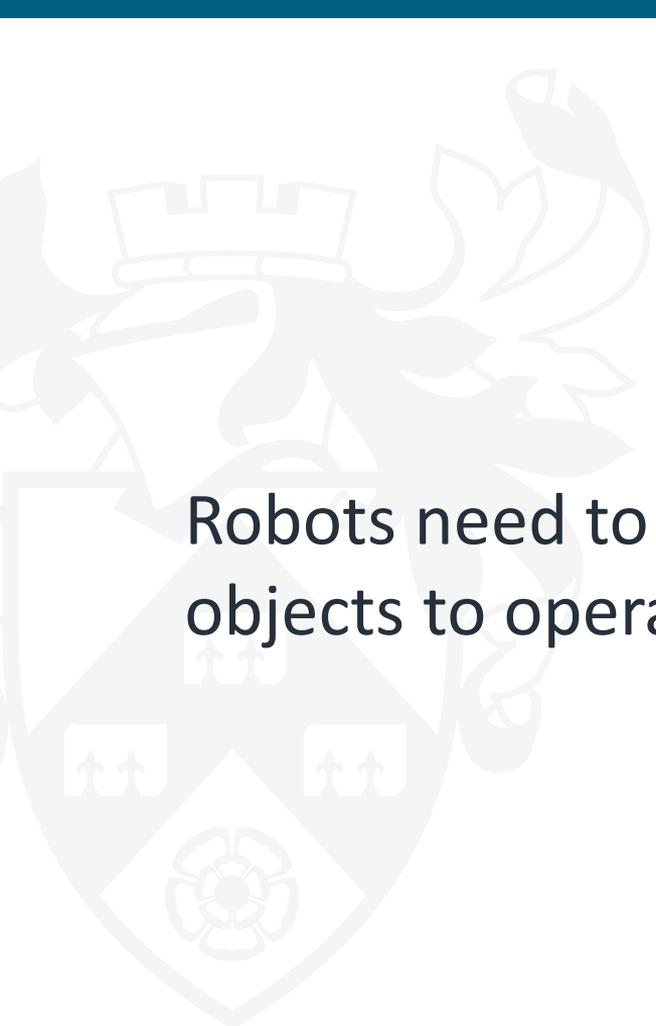
Since 2020

Robots for chemistry

Since 2024

Manipulation of deformable objects

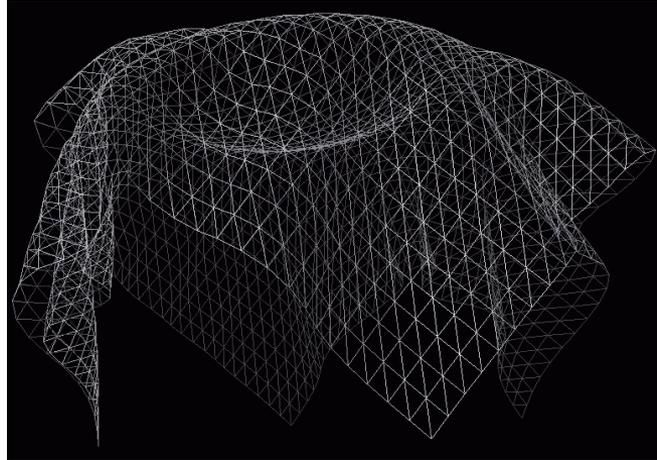




Robots need to be able to handle deformable objects to operate in a human environment.

Deformable vs. rigid: what are the challenges?

1. The complication of **sensing deformation**
2. The curse of **infinite dimensionality** of the deformation configuration
3. The complexity of **high nonlinearity** in modelling the deformation



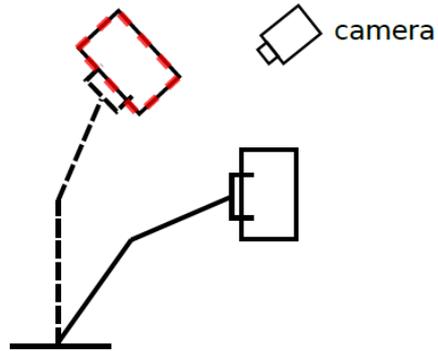
Contact-based manipulation



J. Zhu, B. Navarro, R. Passama, P. Fraise, A. Crosnier and A. Cherubini, Robotic Manipulation Planning for Shaping Deformable Linear Objects With Environmental Contacts, IEEE Robotics and Automation Letters, vol. 5, no. 1, pp. 16-23, Jan. 2020

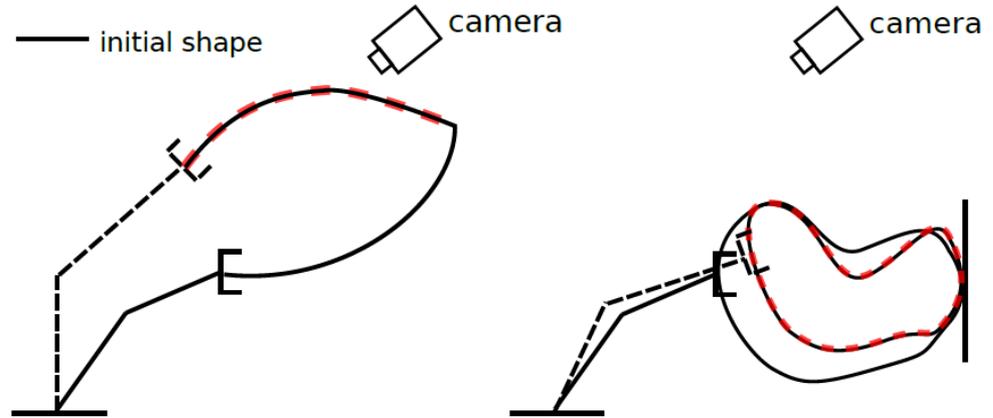
Generalized visual (shape) servo

 Rigid object target shape
 Rigid object initial shape



Servo to the target position and orientation

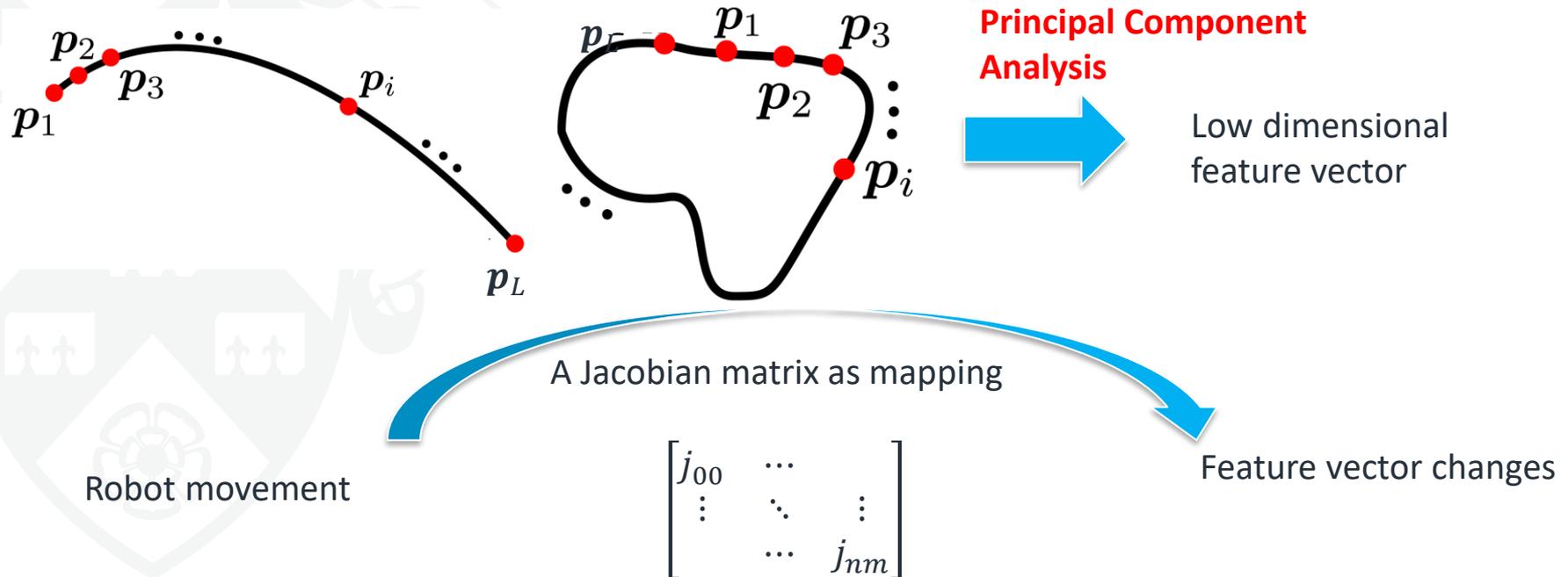
 target shape
 initial shape



Servo to the target shape

Local mapping + controllers

Shape representation (feature vector)



Unified Shape Servo

Vision-based Manipulation of Deformable and Rigid Objects Using Subspace Projections of 2D Contours

J. Zhu¹, D. Navarro-Alarcon², R. Passama¹ and A. Cherubini¹

¹LIRMM University of Montpellier - CNRS, Montpellier, France

²The Hong Kong Polytechnic University
Department of Mechanical Engineering, Hong Kong

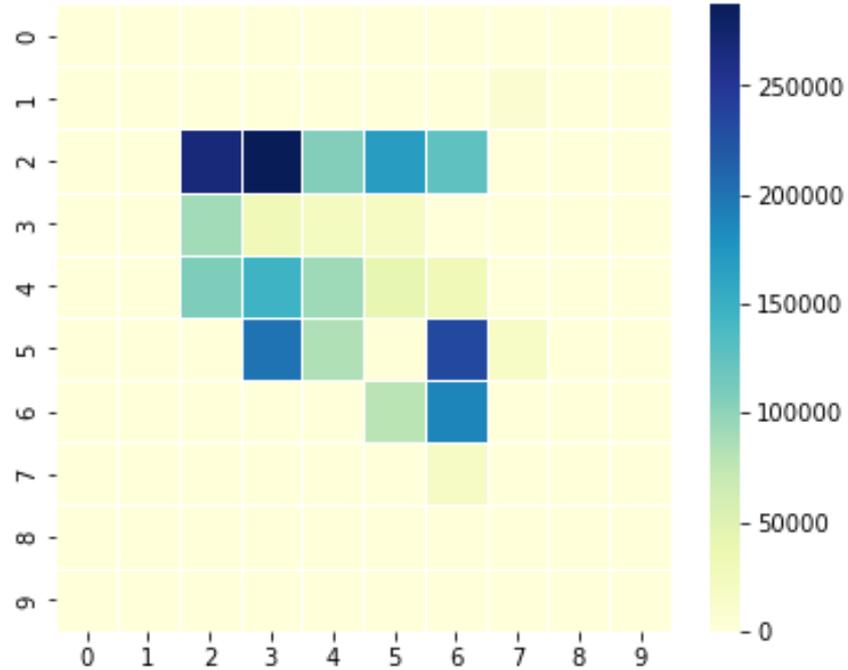
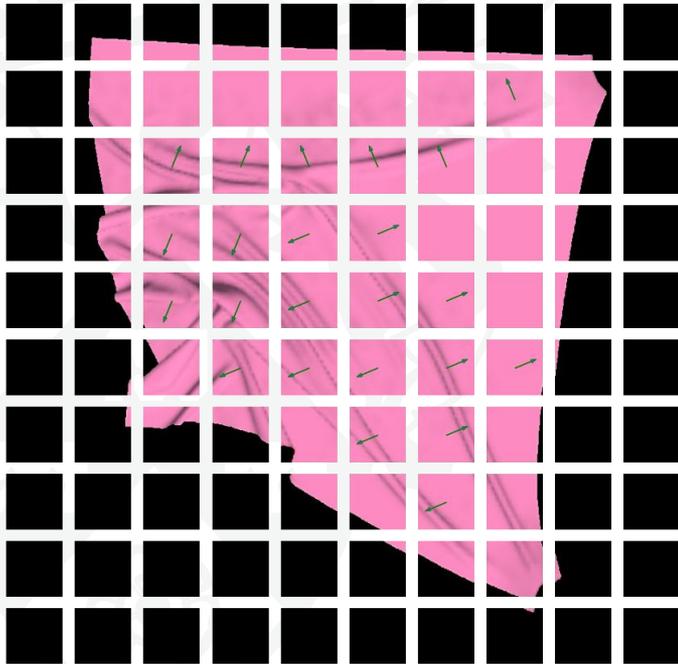
J. Zhu, D. Navarro-Alarcon, R. Passama and A. Cherubini. [Vision-based Manipulation of Deformable and Rigid Objects Using Subspace Projections of 2D Contours](#) Robotics and Autonomous Systems (RAS), vol. 142, pp. 103798, 2021.



Cloth flattening

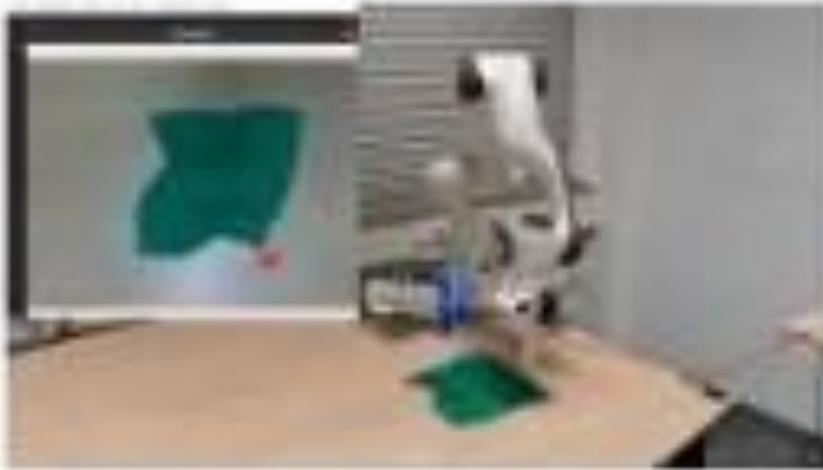
Work by Yulei Qiu

Master in Robotics @TU Delft



Cloth flattening

Heuristic



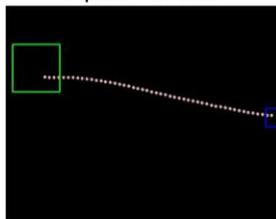
Yulei Qiu

Master in Robotics
@TU Delft

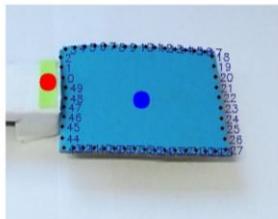
Summary

Infinite dimensionality

Open contour



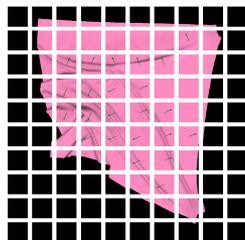
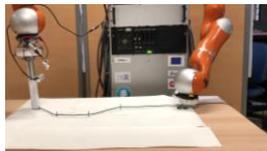
Closed contour



Sampled contour project into eigenspace

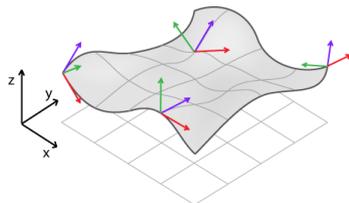
- **Generalized** well to different objects, camera poses

Sensing



Planning with contact to constrain DoFs

High nonlinearity



Compact features from images that are directly usable for control

Using piece-wise local model

- Require **little data for training**
- **Generalized** well to different objects, camera poses

Outlook

Most cited article in IEEE RAM for the past 2 years

Zhu, J., Cherubini, A., Dune, C., Navarro-Alarcon, D., Alambeigi, F., Berenson, D., Ficuciello, F., Harada, K., Kober, J., Li, X., Pan, J. and Yuan, W., Gienger, M., **Challenges and Outlook in Robotic Manipulation of Deformable Objects**. IEEE Robotics and Automation Magazine 2022.



Germany



China



Netherlands



France



The US

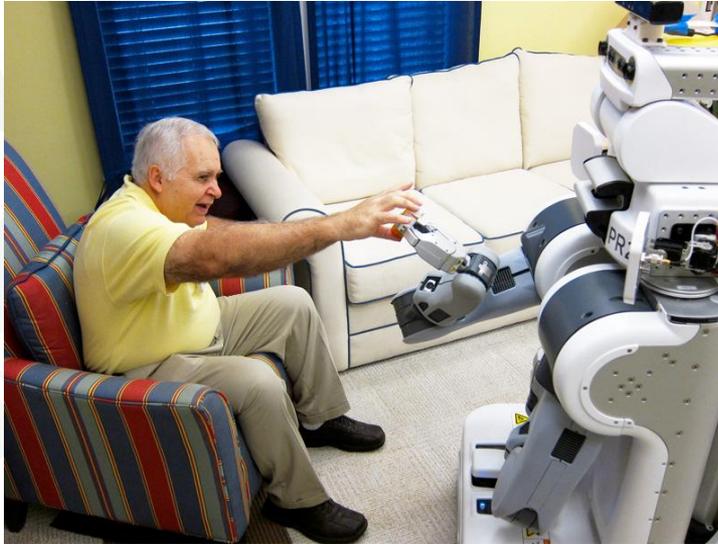


Italy



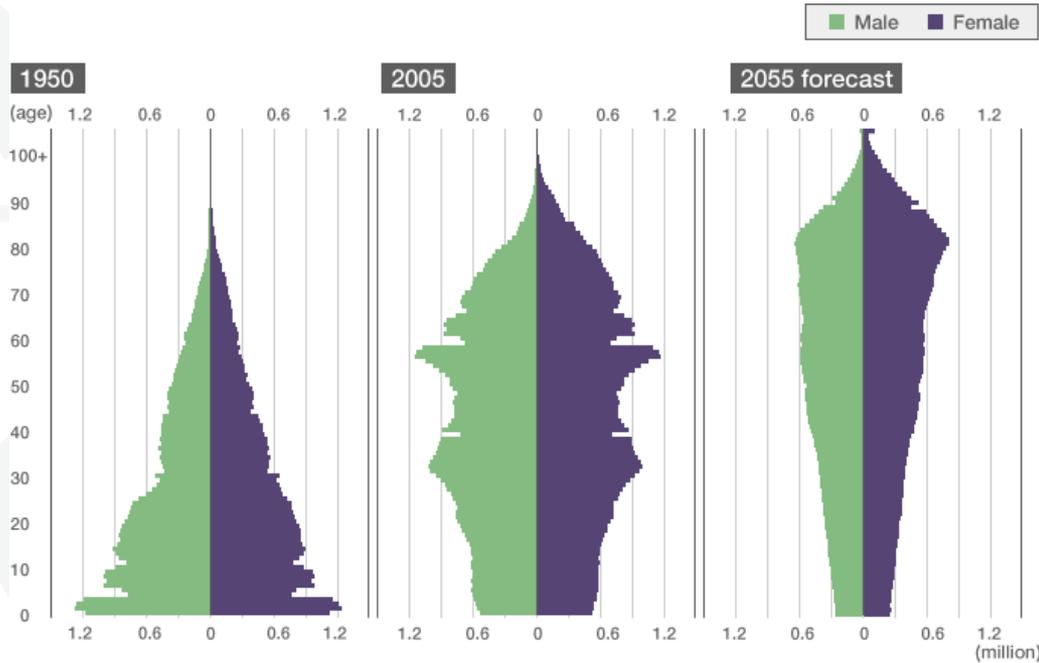
OSAKA UNIVERSITY

Robotic assistance



Motivation

Japan's Rapidly Changing Population Pyramid



Source: National Institute of Population and Social Security Research.

nippon.COM

Care home staff shortage adding pressure on NHS

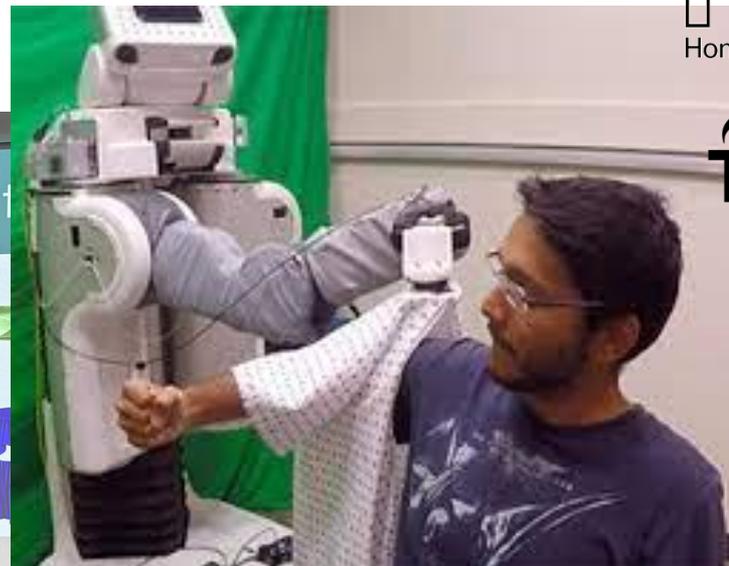
© 3 September 2021

Coronavirus pandemic



A shortage of care home workers in Scotland is adding further pressure on the NHS, the industry has warned.

Dressing assistance: State of the art (around 2021)



Deformable object manipulation for t

Textiles: Clothing, garments, towels, sheets, etc.

- One of the most common and challenging DOs
- Highly complex deformations - effectively infinite degrees of freedom / variations in deformation
- Wrinkling, folding, stretching, self-occluding, drape, ...
- Deformation also dependent on material properties (stiffness, friction, ...)
- Applications in
 - Healthcare: (e.g. robot assistive dressing)
 - Textile recycling
 - Service industry (e.g. laundry folding)
 - Industrial robotics (assembly, fashion)



0.2s horizon

Real time

6



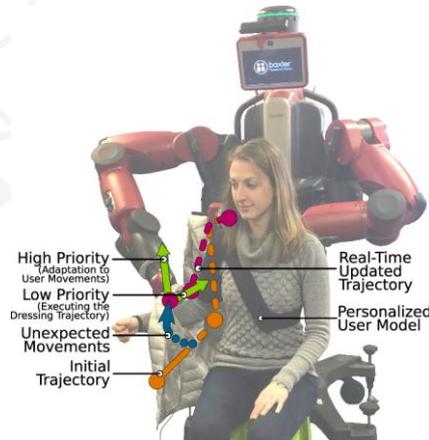
DMANDIC

Kapusta, Ariel, et al. "Personalized collaborative plans for robot-assisted dressing via optimization and simulation." *Autonomous Robots* 43 (2019): 2183-2207.

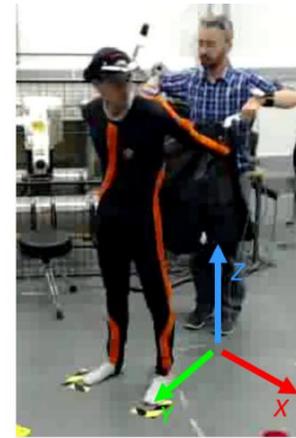
Dressing assistance: State of the art (around 2021)



Li, Shen, et al. "Provably safe and efficient motion planning with uncertain human dynamics." (RSS, 2021).



Zhang, Fan, Antoine Cully, and Yiannis Demiris. "Probabilistic real-time user posture tracking for personalized robot-assisted dressing." *IEEE Transactions on Robotics* 35.4 (2019): 873-888.



Chance, Greg, et al. "'elbows out'—predictive tracking of partially occluded pose for robot-assisted dressing." *IEEE Robotics and Automation Letters* 3.4 (2018): 3598-3605.

Robotic assistive dressing is always considered a single robot task

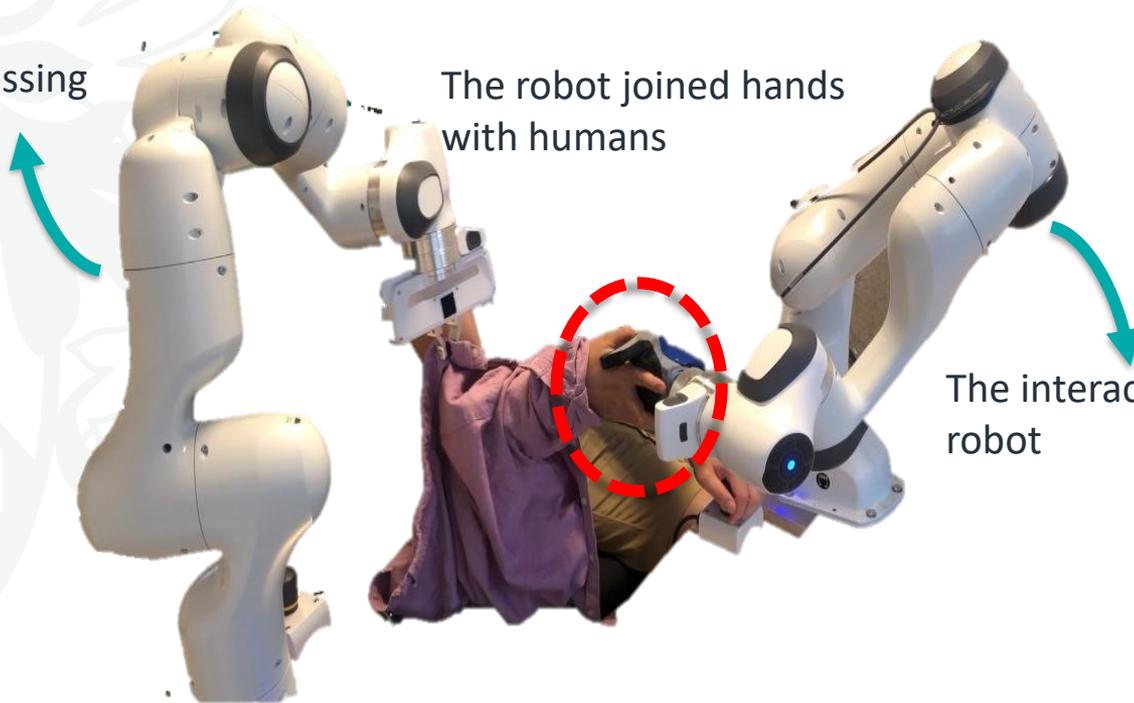
More specifically, previous work considers a **one-robot-to-one-arm** setup

How expert caregivers conduct the task?



Our setup

The dressing
robot



The robot joined hands
with humans

The interactive
robot

Representation for dressing



Key Research Questions

- Manipulation of Deformables/textiles requires Bimanuality
- Capable Hands!
- Efficient representations for manipulation of Deformables
 - See talks of Júlia Borràs Sol and Noémie Jaquier
- Learning manipulation strategies from a few Examples
- Perception for manipulation of Deformables

Rank first in the poll?

Trivial for (some) humans, challenging for (all) robots

KIT

Representation for dressing



Georgia Tech, Healthcare Robotics Lab



Clegg A, Erickson Z, Grady P, et al. Learning to collaborate from simulation for robot-assisted dressing. IEEE Robotics and Automation Letters, 2020, 5(2): 2746-2753.



Yu W, Kapusta A, Tan J, et al. Haptic simulation for robot-assisted dressing 2017 IEEE international conference on robotics and automation (ICRA). IEEE, 2017: 6044-6051.

Representation for dressing

Do we really need the rendering of the full cloth in dressing?



Representation for dressing

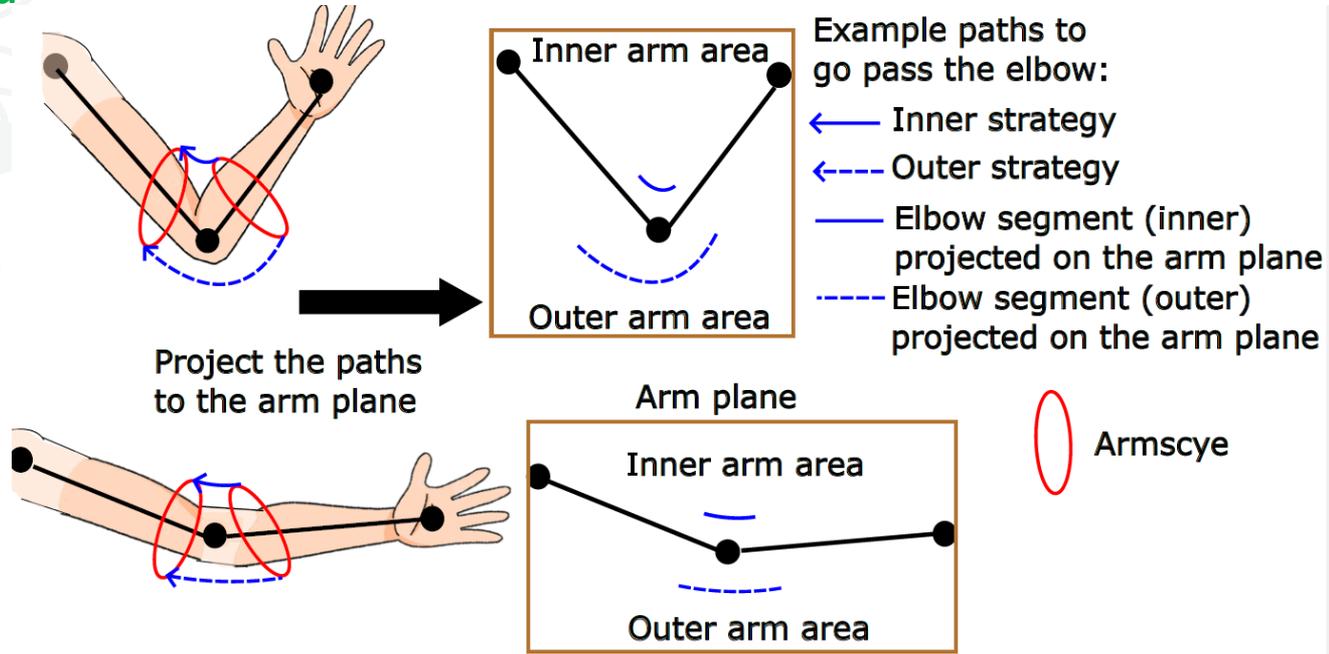


The task of dressing is **to transport the armhole to the shoulder**

Like a hotwire game but...

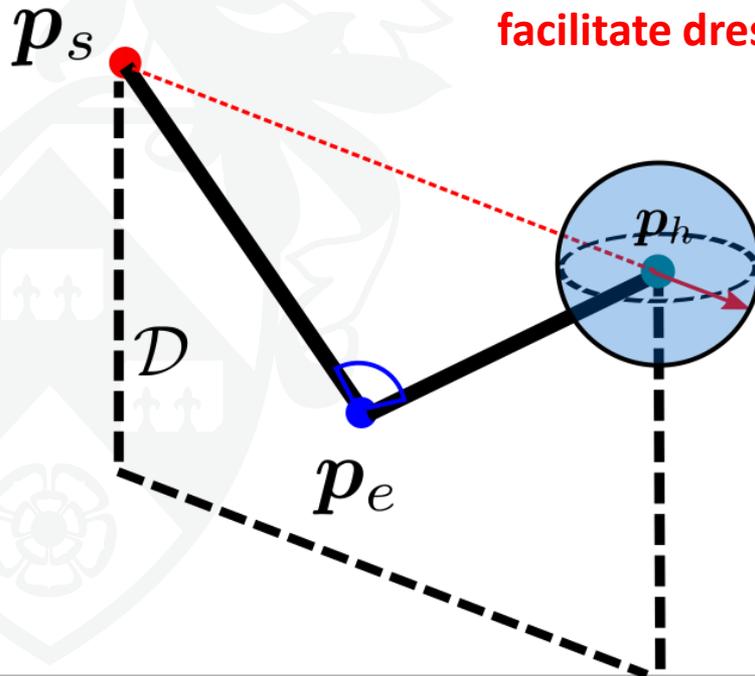
Effect of the elbow angle

Dressing gets complicated around the elbow



Interactive robotic arm: optimal stretch

- How to design policy for the interactive robot to **facilitate dressing**?

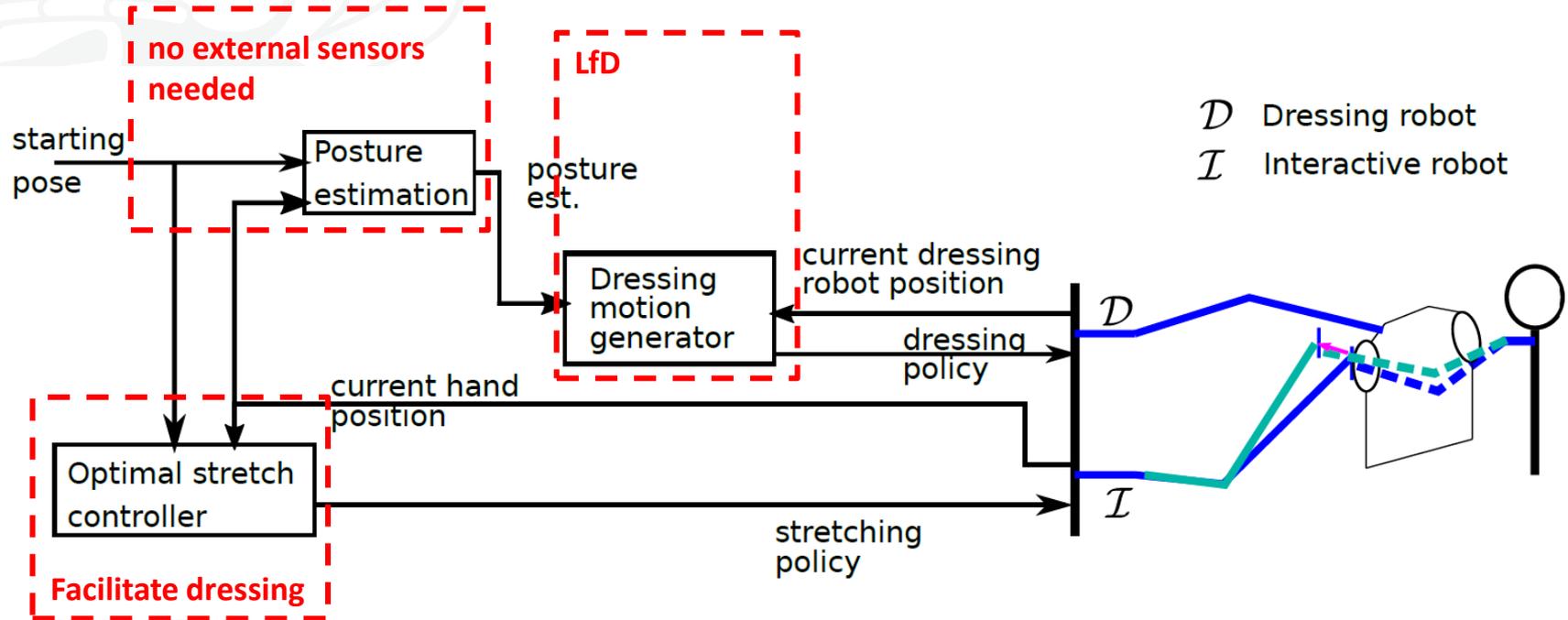


How to guide the human arm to increase the elbow angle as much as possible?

The answer:

The optimal direction is: $\overrightarrow{p_h p_s}$

Framework overview



Bimanual dressing



(Some) Media coverage

14:08
INDEPENDENT

NEWS SPORT VOICES CULTURE LIFESTYLE

News > Health

Two arms are better than one for robot dressers, says researcher

Researchers from York University worked with others from Delft University of Technology in the Netherlands.

Aine Fox • 2 days ago



independent.co.uk

14:09
BBC

NEWS

University of York's new dressing robot mimics care workers

20 hours ago



UNIVERSITY OF YORK

The world's first bimanual dressing robot system mimics how caregivers assist humans in dressing

bbc.co.uk

IEEE Spectrum Video Friday: Acrobot Error

[Hello Robot]

INSPIRED BY CAREGIVING EXPERTS, WE PROPOSED A BIMANUAL INTERACTIVE ROBOTIC DRESSING ASSISTANCE SCHEME, WHICH IS UNPRECEDENTED IN PREVIOUS RESEARCH. IN THE SCHEME, AN INTERACTIVE ROBOT JOINS HANDS WITH THE HUMAN THUS SUPPORTING/GUIDING THE HUMAN IN THE DRESSING PROCESS, WHILE THE DRESSING ROBOT PERFORMS THE DRESSING TASK. THIS WORK REPRESENTS A PARADIGM SHIFT OF THINKING OF THE DRESSING ASSISTANCE TASK FROM ONE-ROBOT-TO-ONE-ARM TO TWO-ROBOT-TO-ONE-ARM.



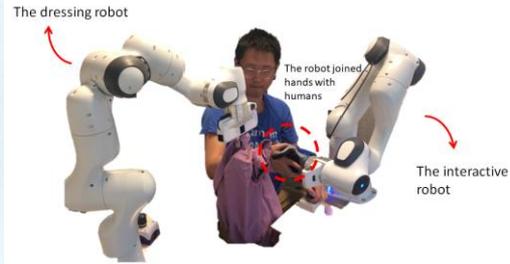
Do You Need a Hand? - a Bimanual Robotic Dressing Assistance Scheme (Sho... Success

[Project]

Deformable object manipulation for textiles

Textiles: Clothing, garments, towels, sheets, etc.

- One of the most common and challenging DOs
- Highly complex deformations - effectively infinite degrees of freedom / variations in deformation
- Wrinkling, folding, stretching, self-occluding, drape, ...
- Deformation also dependent on material properties (stiffness, friction, ...)
- Applications in
 - Healthcare: (e.g. robot assistive dressing)
 - Textile recycling
 - Service industry (e.g. laundry folding)
 - Industrial robotics (assembly, fashion)



IEEE RAS Working Group on DOM

Co-chairs

Jihong Zhu, University of York, UK

Claire Dune, University of Toulon, France

Adrien Koessler, Ecole Nationale d'Ingenieurs de Matz, France

Xiang Li, Tsinghua University, China

Daniel Seita: USC, the US

Júlia Borràs Sol, Institut de Robòtica i Informàtica Industrial (CSIC-UPC)



Institut de Robòtica i
Informàtica Industrial



Recent works on DOM

Multimodal decision making

How can LLMs be fine-tuned to perceive and rank the physical properties of deformable objects (fabrics)?



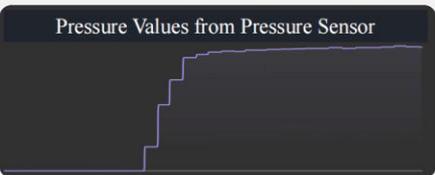
 I'm looking for a plush and stretchable fabric suitable for children's summer dresses. Can you help?

To find a plush and stretchable fabric for children's summer dresses, I will analyze two key properties: 1. **High Elasticity** → Ensures flexibility and comfort, and 2. **High Softness** → Provides a cozy and gentle feel on the skin. So, let me feel each fabric by my hand... 

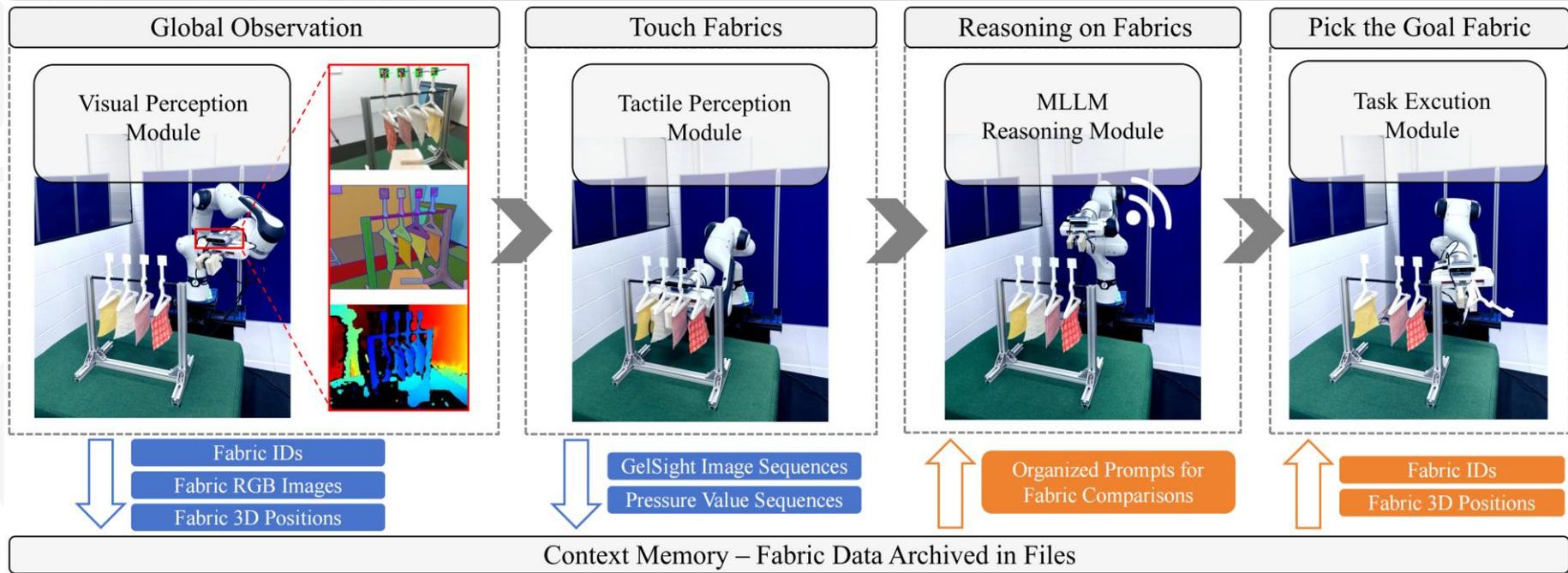
Now, let me reasoning on these data: RGB images, GelSight images, and pressure values... 

Based on the comparisons, **Fabric 2** is the best option for children's summer dresses. Here you go! 

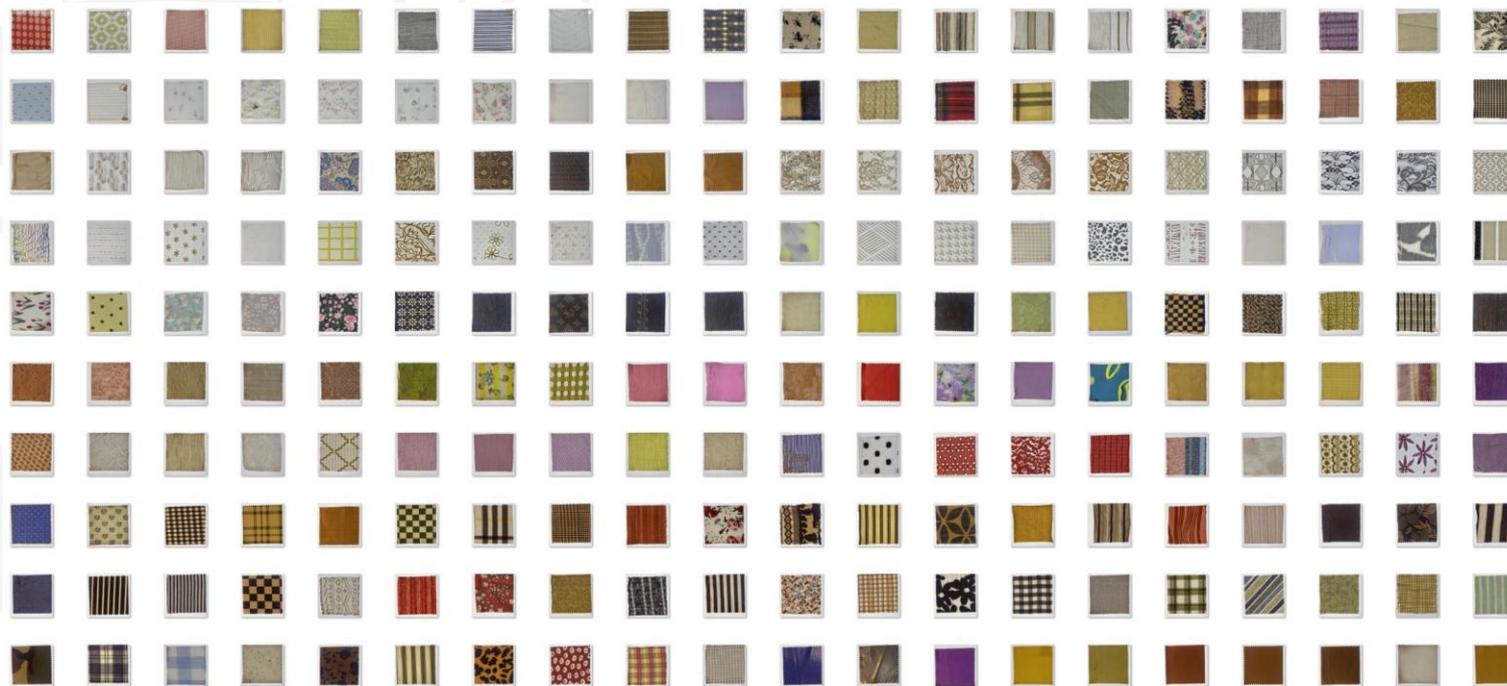
Pressure Values from Pressure Sensor



System Architecture



Fabric Data Set



RGB

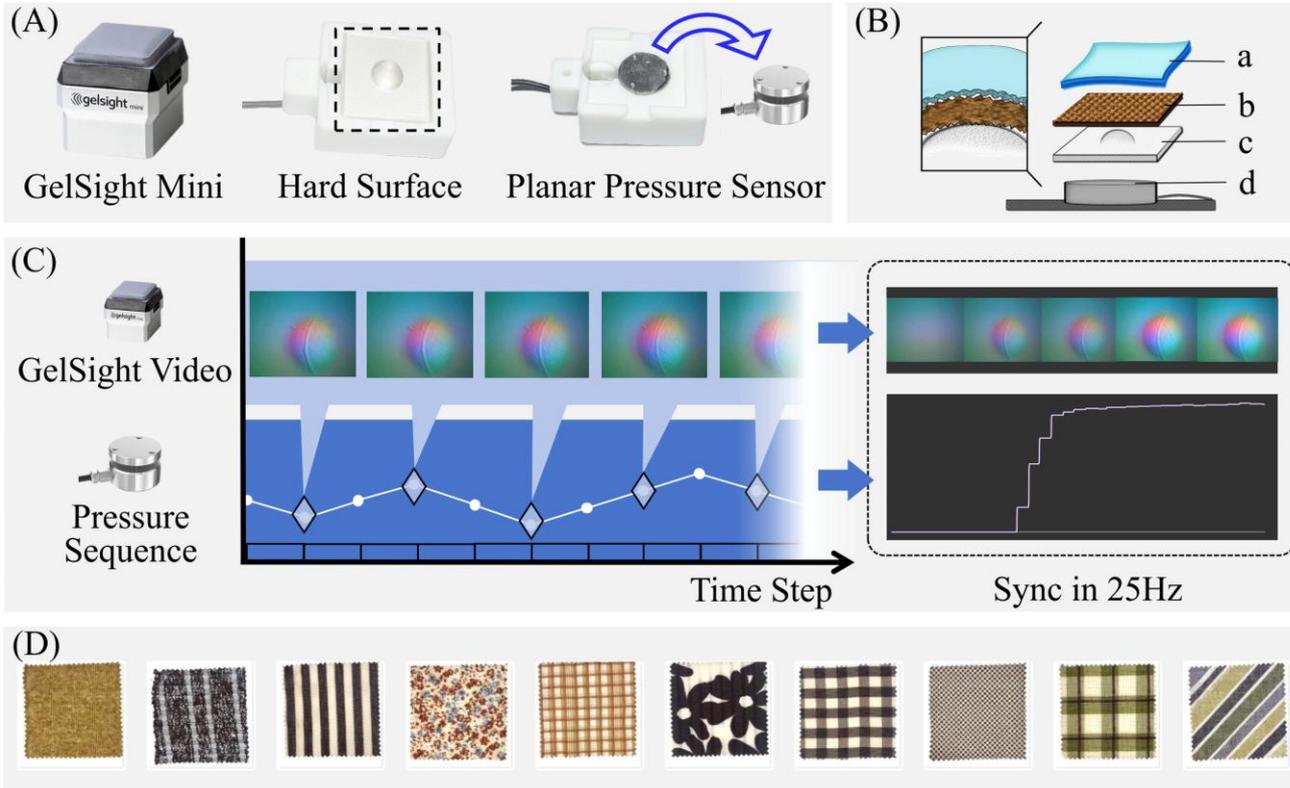
Gelsight video
Sequence

Force applied

Label:

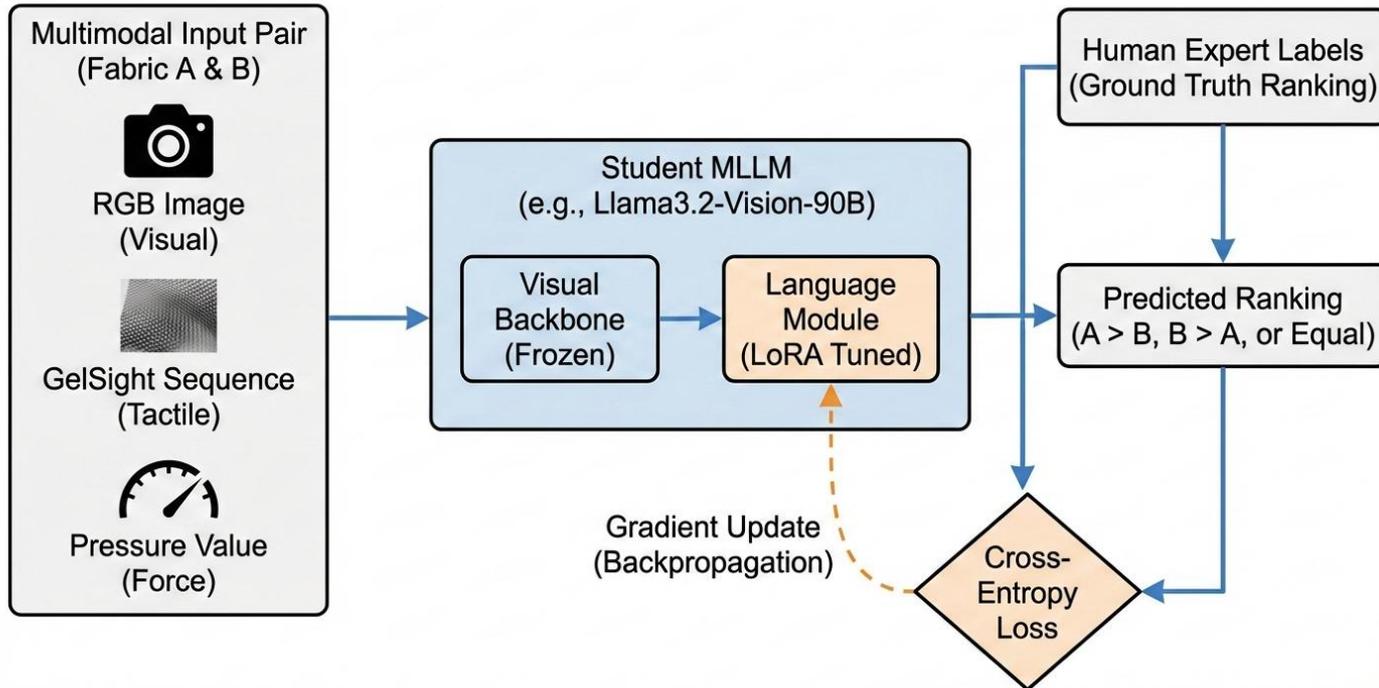
- Elasticity
- Softness
- Texture

Fabric Data Set

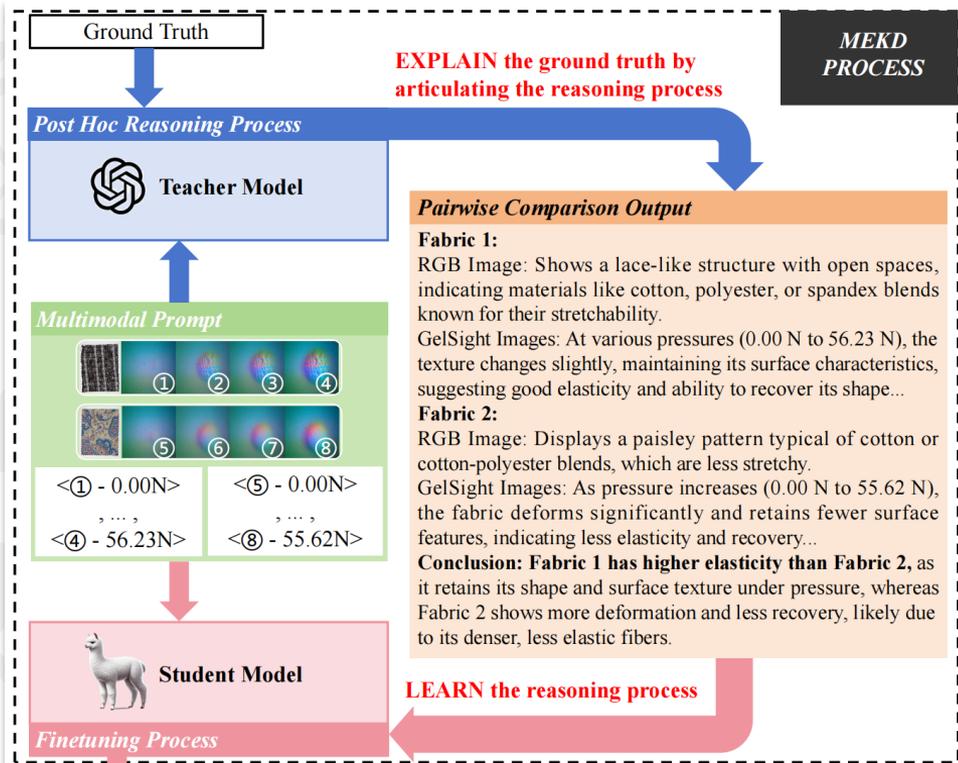


Supervised Fine-Tuning

Directly Supervised Fine-Tuning (D-SFT)



Knowledge Distillation



Improve ranking accuracy
and interpretability

Comparison

Scenario & Properties	Fabric-L90B		GPT-4o		LV90B		CNN IT		CNN IT*		Octopi-13B	
	Sort	Sel	Sort	Sel	Sort	Sel	Sort	Sel	Sort	Sel	Sort	Sel
Athletic wear for flexibility (Elasticity 2, Softness 2)	100%	✓	33.3%	✗	50%	✓	50%	✗	50%	✗	16.7%	✓
Summer dresses for children (Softness 2, Elasticity 2)	83.3%	✓	20%	✓	0%	✗	62.5%	✗	62.5%	✗	16.7%	✓
Light draping fabric for home decor (Thickness 1, Softness 2)	66.7%	✓	20%	✗	50%	✗	37.5%	✗	37.5%	✗	33.3%	✗
Durable fabric for frequent-use furniture (Texture 2, Thickness 1)	62.5%	✓	28.5%	✗	62.5%	✓	62.5%	✓	62.5%	✓	37.5%	✓
Protective fabric for work environments (Thickness 1, Elasticity 0)	50%	✓	50%	✗	50%	✗	25%	✗	25%	✗	30%	✗
Heavy-duty material for robust applications (Texture 2, Thickness 2)	75%	✓	33.3%	✗	25%	✗	37.5%	✓	37.5%	✓	25%	✓
Soft lining fabric for formal suits (Thickness 0, Softness 2, Texture 0)	80%	✗	42.8%	✗	30%	✗	50%	✓	50%	✓	10%	✗
Lightweight smooth fabric for formal shirts (Thickness 0, Softness 2, Texture 0)	90%	✓	45%	✗	9.1%	✗	75%	✓	75%	✓	36.3%	✗
Ultra-soft lightweight fabric for accessories (Softness 2, Thickness 0)	50%	✓	50%	✗	16.7%	✗	75%	✓	75%	✓	16.7%	✗
Thick, luxurious fabric for premium interiors (Thickness 2, Elasticity 0, Texture 2)	61.5%	✗	23%	✗	15.3%	✗	41.6%	✗	41.6%	✗	38.4%	✗

Sort: Piece-wise comparison accuracy

Sel: Final selection accuracy

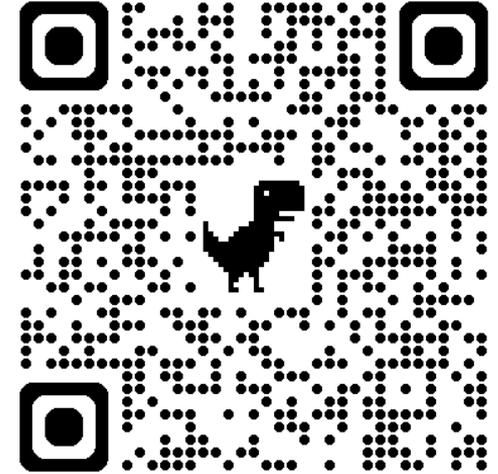
Robotics Fabric Selection

MLLM-Fabric: Multimodal Large Language Model-Driven Robotic Framework for Fabric Sorting and Selection

Liman Wang, Hanyang Zhong, Tianyuan Wang, Shan Luo, and Jihong Zhu

More info

L. Wang, H. Zhong, T. Wang, S. Luo and J. Zhu, "MLLM-Fabric: Multimodal Large Language Model-Driven Robotic Framework for Fabric Sorting and Selection," in *IEEE Robotics and Automation Letters*, vol. 10, no. 12, pp. 13137-13144, Dec. 2025



 <https://github.com/limanwang/MLLM-Fabric>

 <https://huggingface.co/datasets/EuniceF/MLLM-Fabric>

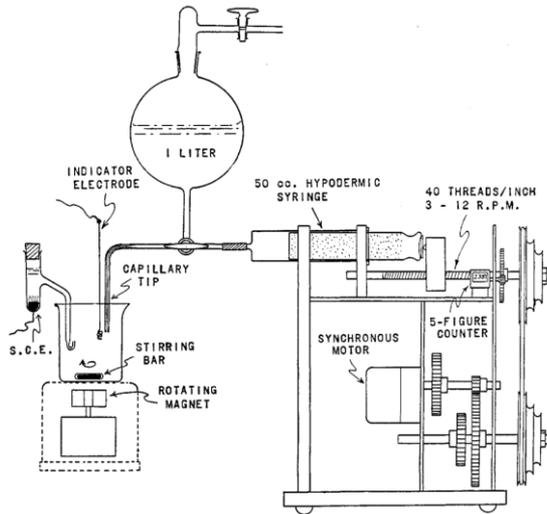
On-going work on sliding





Robotic Chemistry

Lab Automation



 FLOWPILOT



Robot chemists, Lunt et al. 2024

TARMAC: A TAxonomy for Robot MAnipulation in Chemistry

<https://tarmac-paper.github.io/>



Teaching lab videos



91 Videos, 273 minutes of video recording

Chemistry Teaching Lab

Task segmentation & Annotation



Pull Cap



Insert Funnel



Pour Solvent

Feature Extraction

Force dependency

Force is required to complete the task or as ending signal



Feature Extraction

Motion Pattern

The task is an one-off motion
or
repetitive and cyclic motion



Feature Extraction

Control Directness

The target object is directly controlled or through an intermediate object



Taxonomy Formation

Force Dependent	Indirect Control	Repetitive Motion	Count ↓	Taxonomic Category
✓	✗	✗	198	Coupling
✗	✗	✗	169	Positioning
✗	✓	✗	73	Tooling
✓	✓	✗	64	
✗	✗	✓	44	Agitating
✗	✓	✓	13	
✓	✗	✓	1	
✓	✓	✓	0	

Taxonomy Formation

Positioning

- Static
- Rotational
- Insertive
- Sliding

Coupling

- Linear
- Rotational
- Elastic
- Penetrative

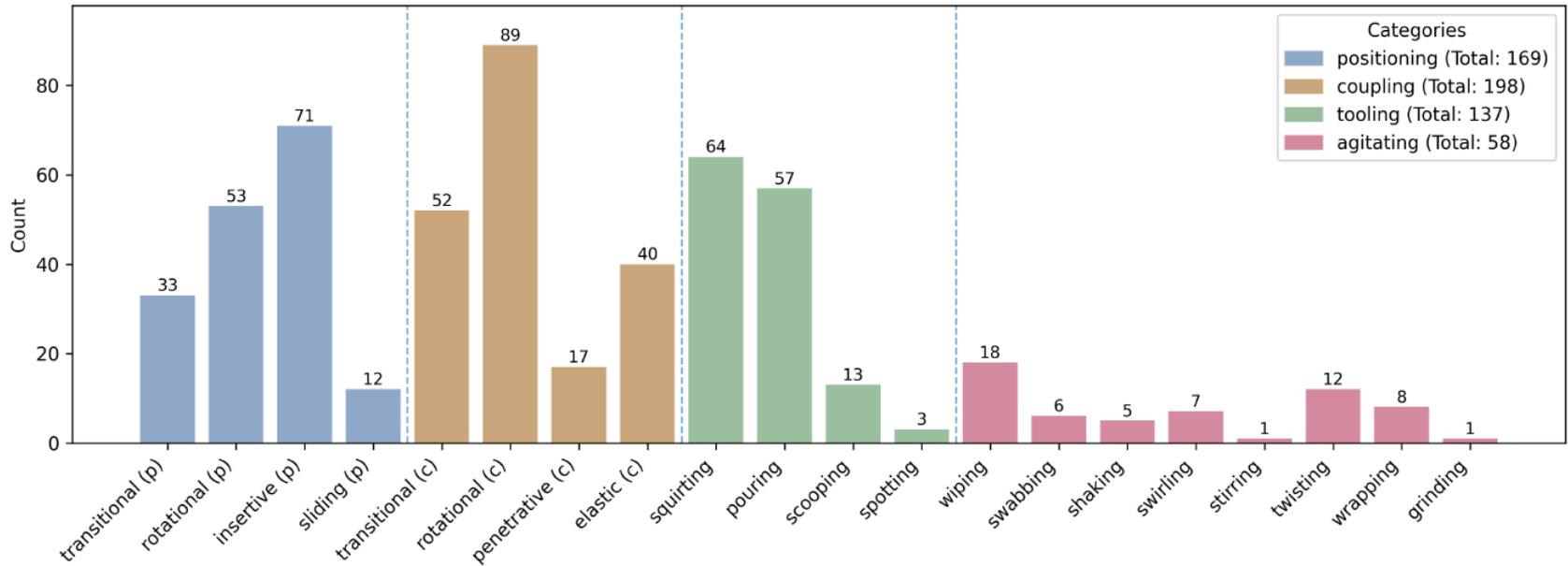
Agitating

- Shaking
- Swirling
- Stirring
- Twisting
- Wiping

Tooling

- Scooping
- Spotting
- Pouring
- Squirting
- Dropping

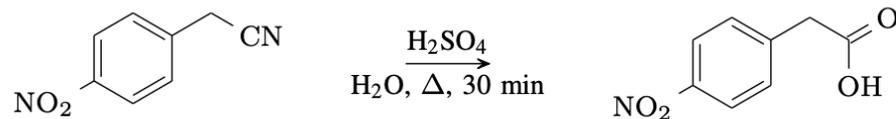
Taxonomy Analysis – Distribution



Taxonomy Analysis – Task

Decomposition

Experiment: Hydrolysis of a nitrile



A 9 M solution of sulfuric acid in water was carefully prepared in a conical flask. A 100 mL single-neck round-bottomed flask with a stirrer bar was charged with 4-nitrophenylacetonitrile followed by 9 M sulfuric acid (25 mL) and the suspension was refluxed for 30 minutes. After this time, the solution was allowed to cool to room temperature before the addition of water (25 mL) and cooling in an ice-bath. The crude product was collected via vacuum filtration. The crude solid was dissolved in ethyl acetate (20 mL) and extracted with 2 M sodium hydroxide solution (20 mL). The two layers were separated, and the aqueous layer was acidified with 3 M hydrochloric acid (20 mL) and extracted with ethyl acetate (20 mL). The organic layer was dried over magnesium sulfate, filtered and concentrated to yield the product which was recrystallised from 20% ethanol in water.

Taxonomy Analysis – Task Decomposition

Action needed to conduct experiments	Taxonomy Category	Taxonomy action
A magnetic stirrer bar was placed in round bottom flask (RBF)	Positioning	Insertive positioning
0.486 g 4-nitrophenylacetonitrile was weighed onto weighing boat	Tooling	Scoping
Weighing boat was tipped into RBF	Tooling	Pouring

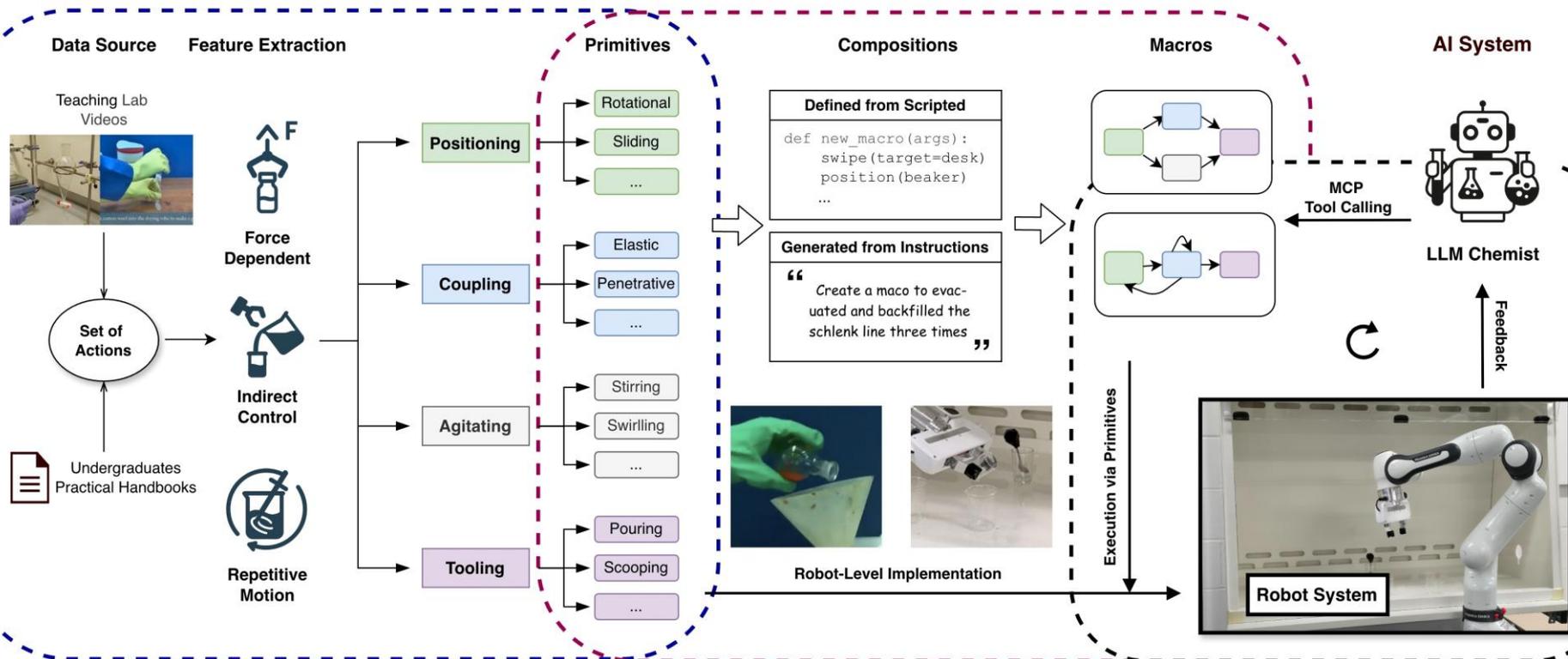
Action needed to conduct experiments	Taxonomy Category	Taxonomy action
A magnetic stirrer bar was placed in round bottom flask (RBF)	Positioning	Insertive positioning
0.486 g 4-nitrophenylacetonitrile was weighed onto weighing boat	Tooling	Scoping
Weighing boat was tipped into RBF	Tooling	Pouring
25 mL of sulfuric acid solution was added to RBF	Tooling	Pouring
Condenser added to the top of RBF	Positioning	Insertive positioning
Suspension was heated to reflux for 30 minutes.		
Condenser was removed	Positioning	Transitional positioning

Stopper placed on top of separating funnel.	Coupling	Force Coupling
Separating funnel shaken.	Agitating	Shaking
Stopper removed from separating funnel.	Coupling	Force Coupling
Beaker placed underneath separating funnel.	Positioning	Transitional positioning
Tap of separating funnel opened to remove 1st layer.	Positioning	Rotational Positioning
New beaker placed underneath separating funnel.	Positioning	Transitional positioning
Tap of separating funnel opened to remove 2nd layer.	Positioning	Rotational Positioning
Beaker placed underneath separating funnel removed.	Positioning	Transitional positioning
Magnesium sulfate added to beaker to reach 'snow globe effect'.	Tooling	Scoping
Funnel placed on top of new RBF.	Positioning	Insertive positioning
Contents of beaker poured into sinter funnel.	Tooling	Pouring
Funnel removed from RBF.	Positioning	Transitional positioning
RBF attached to rotary evaporator to remove solvent.	Positioning	Insertive Positioning
Product from RBF scraped into conical flask.	Tooling	Scoping
Conical flask placed on hotplate.	Positioning	Static positioning
20% ethanol in water mixture added dropwise to conical flask.	Tooling	Squirting
Solid dissolved in the flask.	Agitating	Swirling

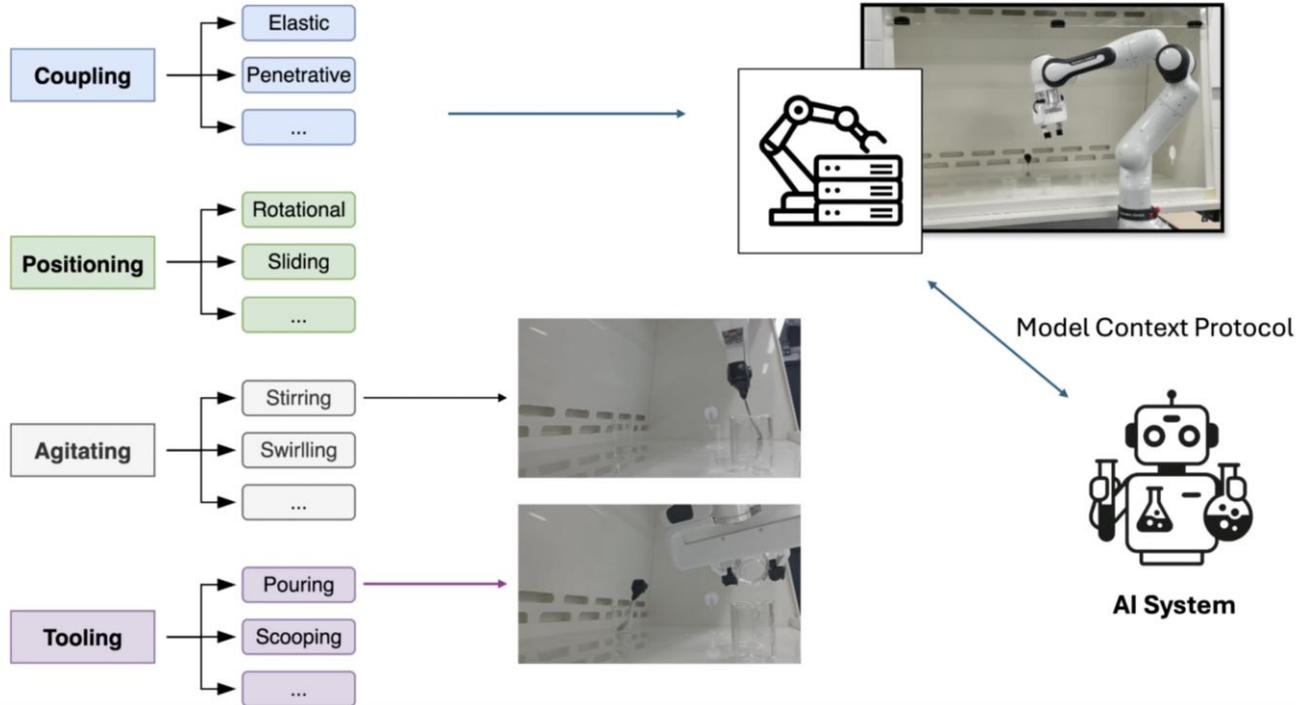
Taxonomy overview

Taxonomy for Robot Manipulation in Chemistry

Taxonomy-based Robotic Framework



Taxonomy Enabled Robot Actions



Demo



Demo



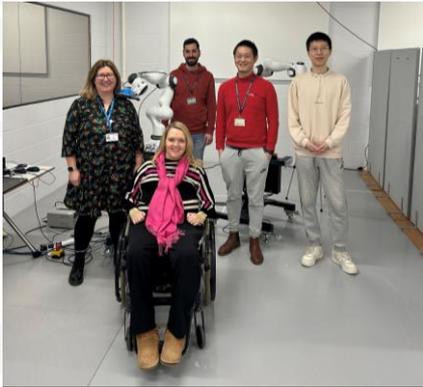
More info

Huang, K., Pipe, J., Martin, A. E., Wang, T., Franklin, B. A., Tyrrell, A. M., Fairlamb, I.S.J., & Zhu, J. (2025). TARMAC: A Taxonomy for Robot Manipulation in Chemistry. arXiv preprint arXiv:2510.19289. (Under revision for Nature Communications Chemistry)



Current Research

Assistive Robotics



**BREAST
CANCER
NOW** The research &
support charity



In collaboration with **York and Scarborough
Teaching Hospitals**
NHS Foundation Trust



Andy McDonald MP,
on behalf of Spinal Injuries Association
requests the company of

lihong Zhu

for a Roundtable event on **'Women's health with SCI'**
Co-chaired by **Gill Furniss MP**
in the Thatcher Room at Portcullis House
on 24th February 2025 at 1pm to 3pm
Address: UK Parliament, Westminster, London SW1A 0AA

Invitation to the Parliament

Current Research

AI Scientist



With Prof. Ian Fairlamb,
(Chemistry)

> **Alchemy**
AI FOR CHEMISTRY

In collaboration with

EPSRC
Engineering and Physical Sciences
Research Council

 **UNIVERSITY OF
LIVERPOOL**

 **University of
Sheffield**

One Postdoc opens around Sept this year in robotic chemistry



Thank you
Any questions?

