ROMANDIC

SCAN ME!

BENCHMARKING CLOTH MANIPULATION: ENABLING COMPARISON THROUGH STANDARDIZATION

IRENE GARCIA-CAMACHO

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

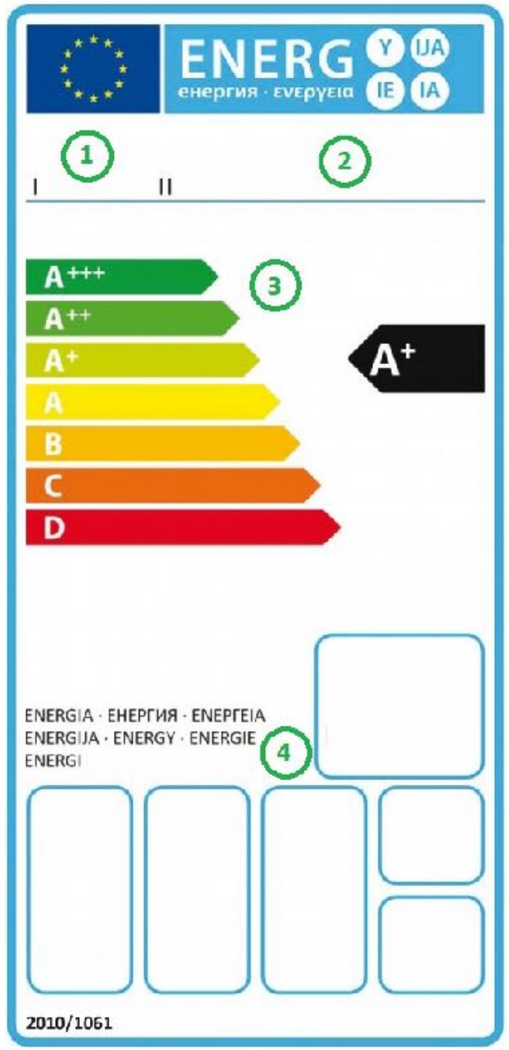
Institut de Robòtica i Informàtica Industrial

HOW CAN WE ASSES ROBOTIC MANIPULATION SYSTEMS?

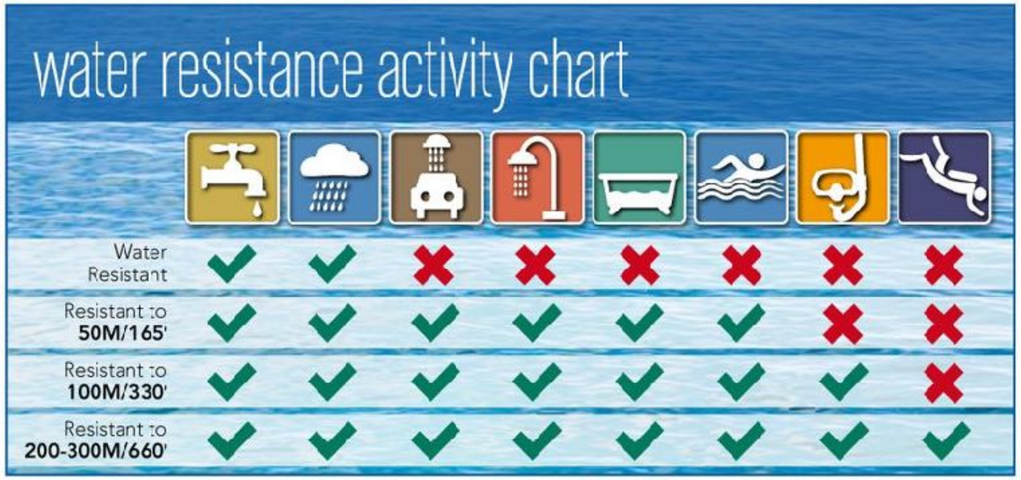
BENCHMARK:

“Systematic standard process for evaluating something by comparison”

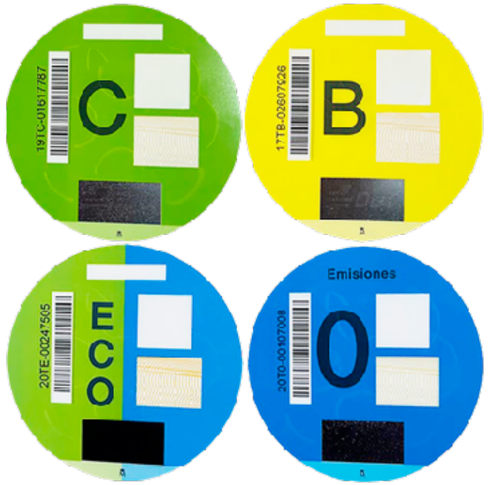
BENCHMARK STANDARDS



Energy efficiency



Water resistant



Environmental car emisions

Cybersecurity level

ISO standards

BENCHMARKS AND DATABASES IN ROBOTICS

Machine learning

BENCHMARK SUITE RESULTS

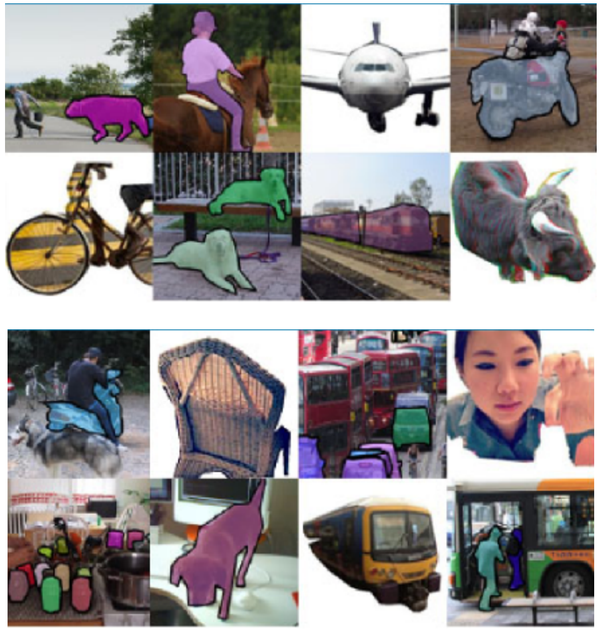
MLPerf Training

Benchmark suit for
ML models

GLUE

Benchmark resources for
natural language systems

Computer Vision

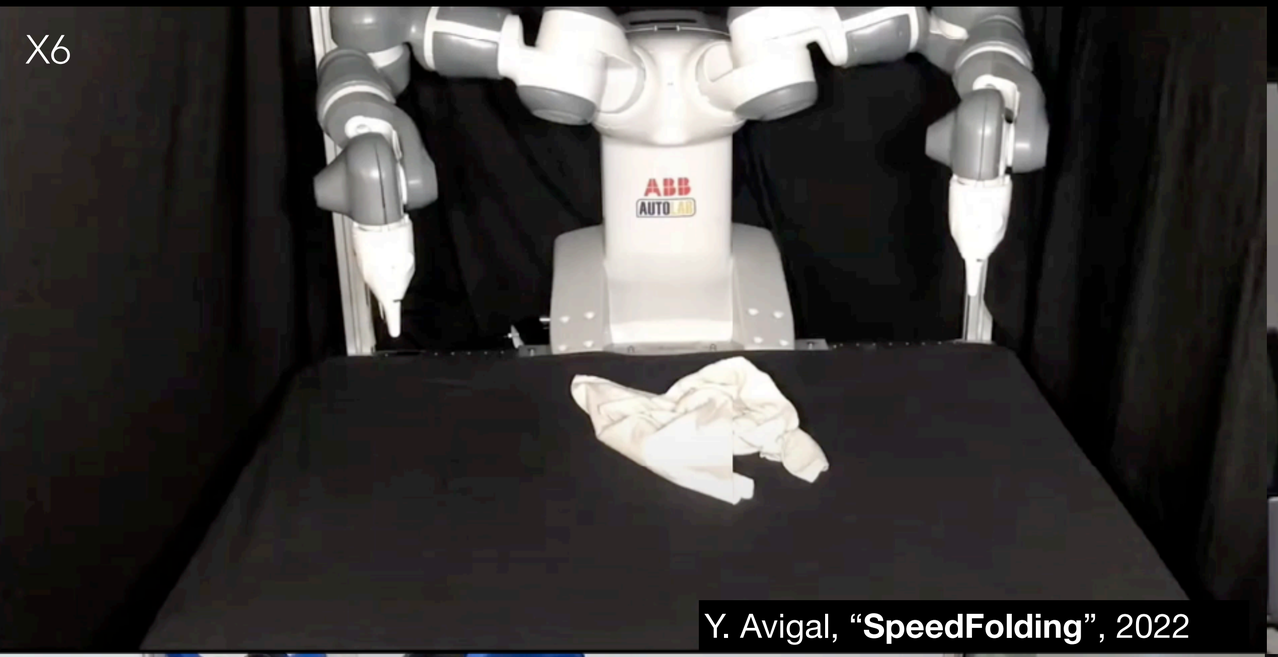


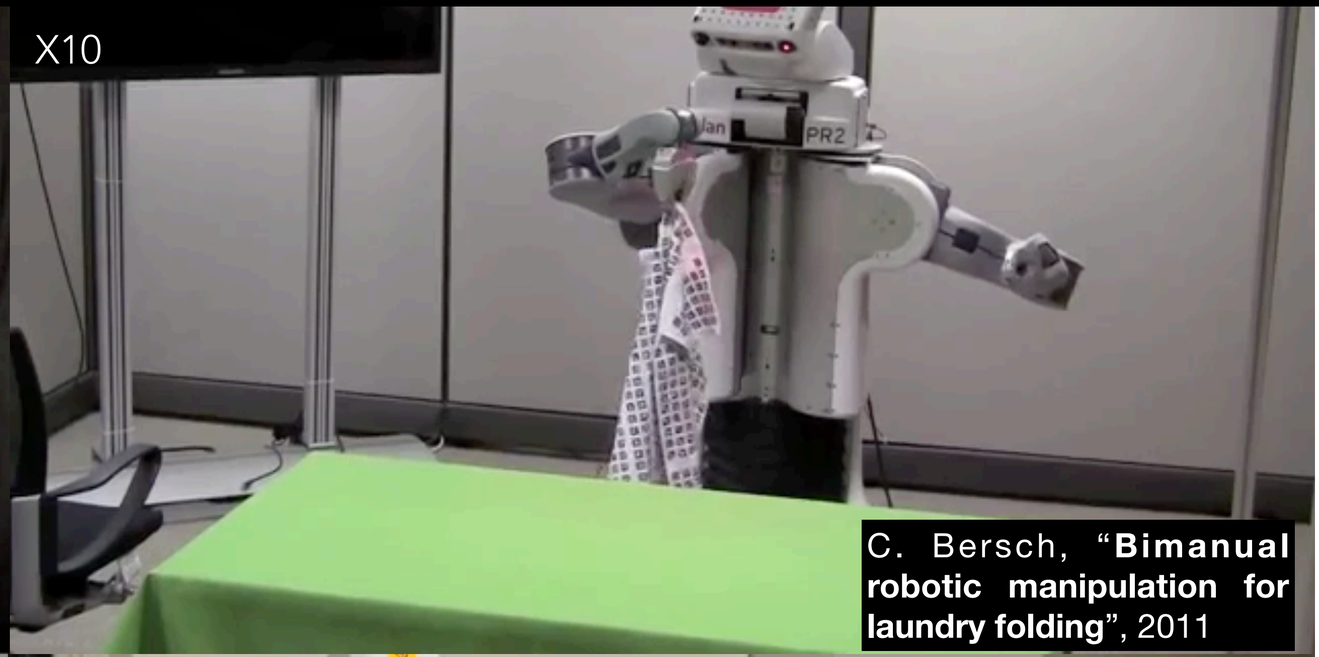
COCO
(Object detection
and segmentation)

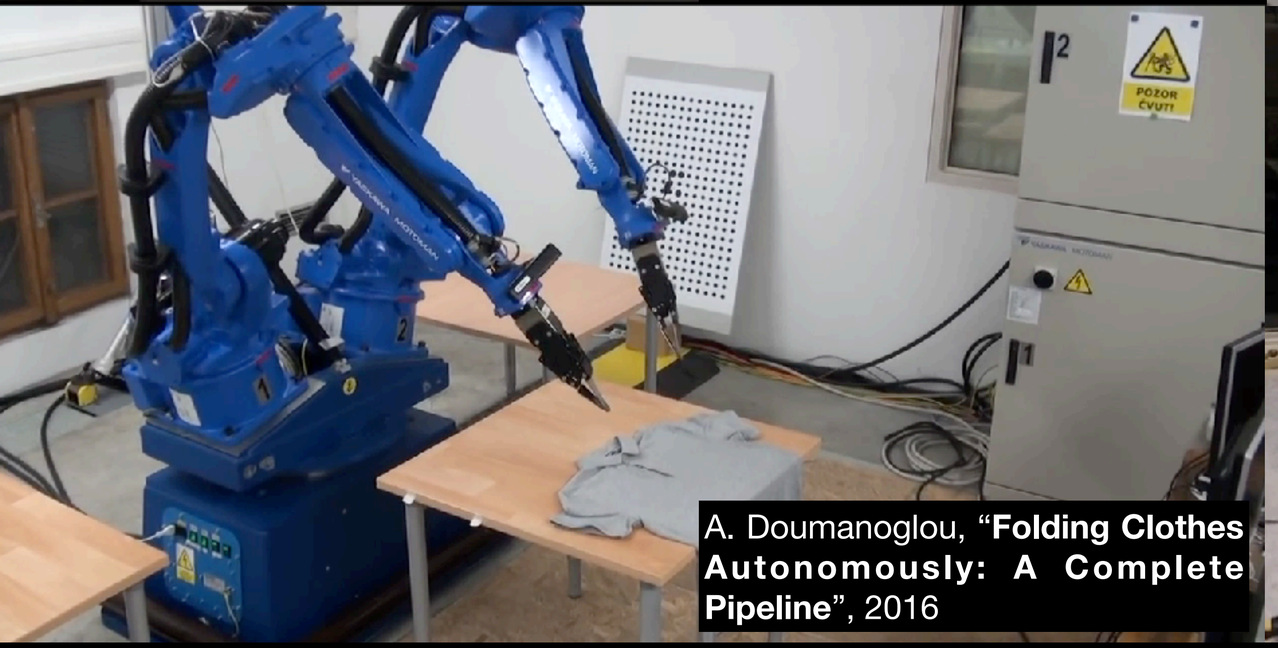
Cloth manipulation

ClothesNet
(Simulated coth object dataset)

HOW CAN WE DESIGN BENCHMARKS FOR CLOTH MANIPULATION?


X6
ABB
AUTOLAB
Y. Avigal, “**SpeedFolding**”, 2022

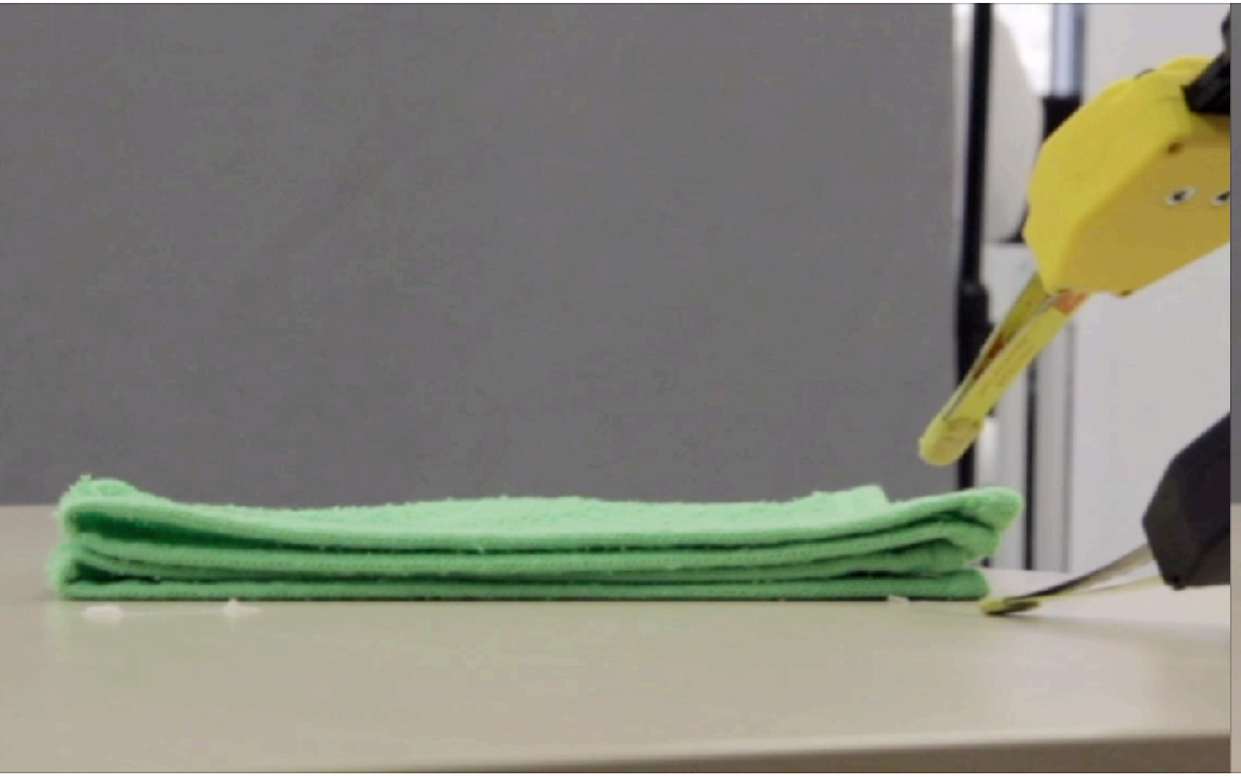

X10
Jan
PR2
C. Bersch, “**Bimanual robotic manipulation for laundry folding**”, 2011

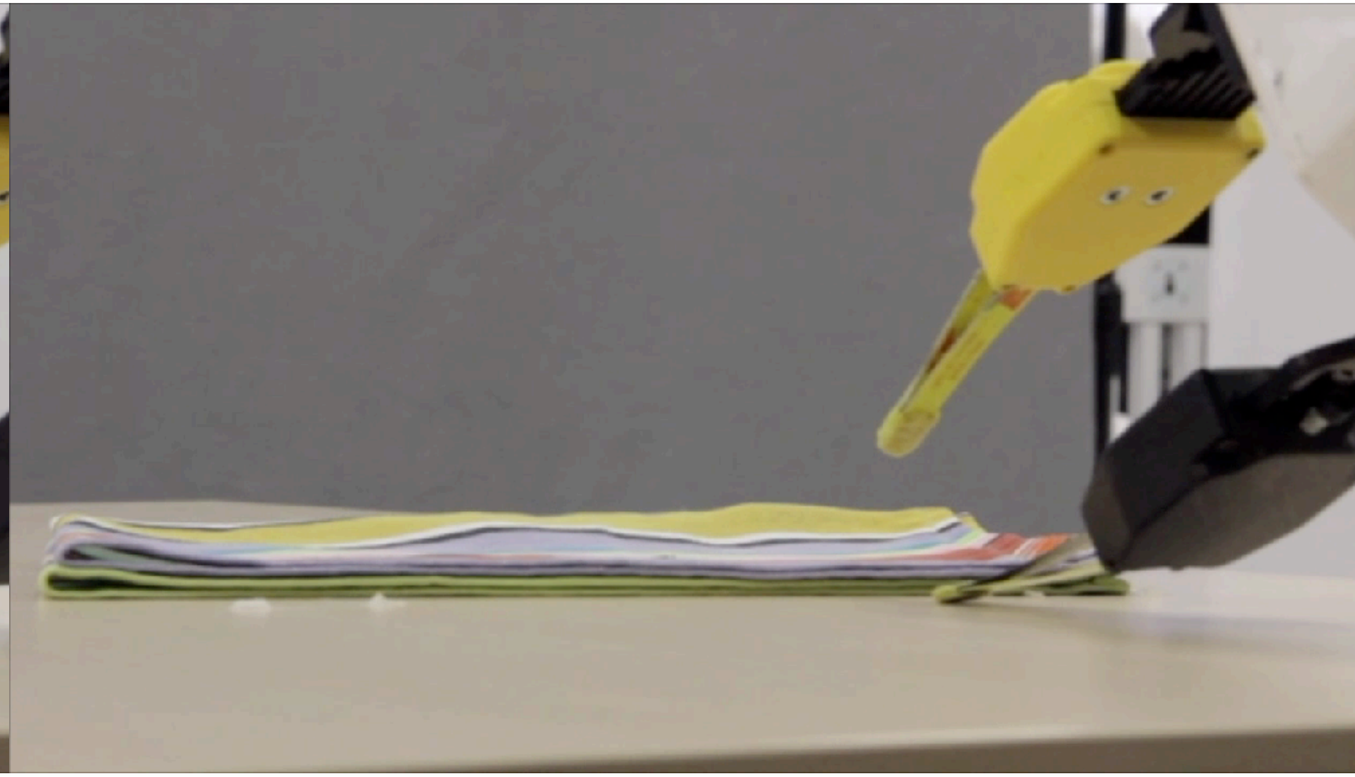

POZOR
ČVUTI
A. Doumanoglou, “**Folding Clothes Autonomously: A Complete Pipeline**”, 2016


E. Honnold, “**Robotic laundry folding**”, 2018

OBJECT SETS FOR MANIPULATION

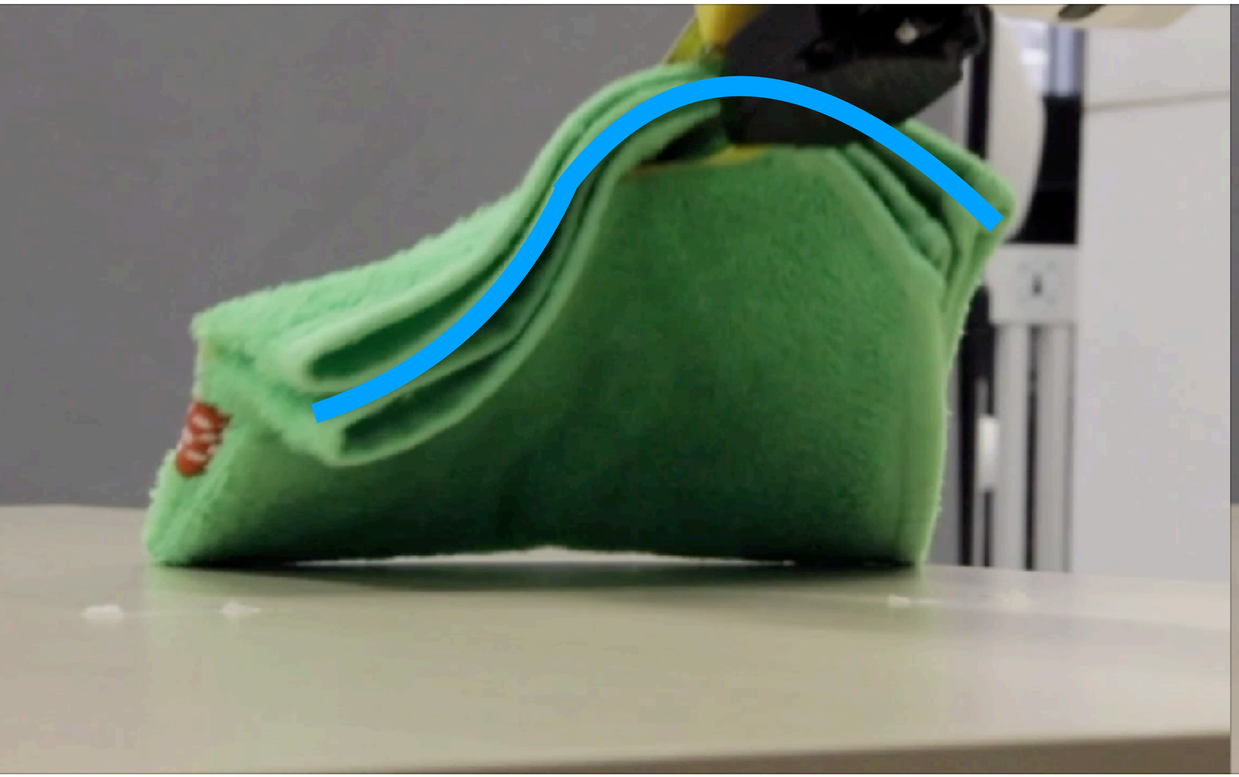
Same manipulation but different behavior





OBJECT SETS FOR MANIPULATION

Same manipulation but different behavior



OBJECT SETS FOR MANIPULATION

The experimental results of the first grasping experiment are shown in Table 1. Overall, the grasping success rate varies from 76.7% to 93.3% on different types of clothing. This difference can be attributed into the difference of clothes materials. In other words, the thickness and stiffness variation of clothes' materials brings different challenges to grasping. Specifically, the sweaters and t-shirts performed the best (93.3%,90%) while jeans and shirts obtained the lowest scores (78.3%,76.7%). The reason is two-fold: firstly, the more stiff the clothing material is, the more difficult the grasping is; and also, the more wrinkles the clothing configuration has, the easier the grasping is. On average, the proposed

Sun et. al. 2018

Fig. 9: Our test set of clothing articles.

Cusumano et. al. 2011

V. EXPERIMENTS

After tuning the parameters on a training set of 3 towels[7], we ran 50 trials over a wide variety of previously unseen towels. In particular, the test set comprised 25 distinct colors/patterns, 16 distinct materials, and 11 distinct sizes (with lengths ranging from 32 to 78 cm and widths ranging from 32 to 48 cm).[8] Each of the 25 towels in the test set

Maitin et. al. 2010

Fig. 6: The cloths we use for experiments. We use the gray towel (left) for training, and test on all 3 cloths for evaluation. The white towel and patterned cloth test generalizing to novel cloths. The cloths have thicknesses between 3-5 mm and variation in surface texture and stiffness.

Tirumala et. al. 2022

D. Generalization to Unseen Garments

We explore how SpeedFolding, trained on a single t-shirt, can generalize to garments unseen during training. In these experiments we use (1) a t-shirt with a different color and stiffness and (2) a rectangular towel with a different color compared to the original t-shirt. We evaluate SpeedFolding

Avigal et. al. 2022

OBJECT SETS FOR MANIPULATION

Jia et. al. 2017

Ha et. al. 2021

Maitin et. al. 2010

Ganapathi et. al. 2021

Salleh et. al. 2006

Ha et. al. 2021

Maitin et. al. 2010

Weng et. al. 2021

Zacharia et. al. 2008

Estevez et. al. 2017

Tirumala et. al. 2022

Avigal et. al. 2022

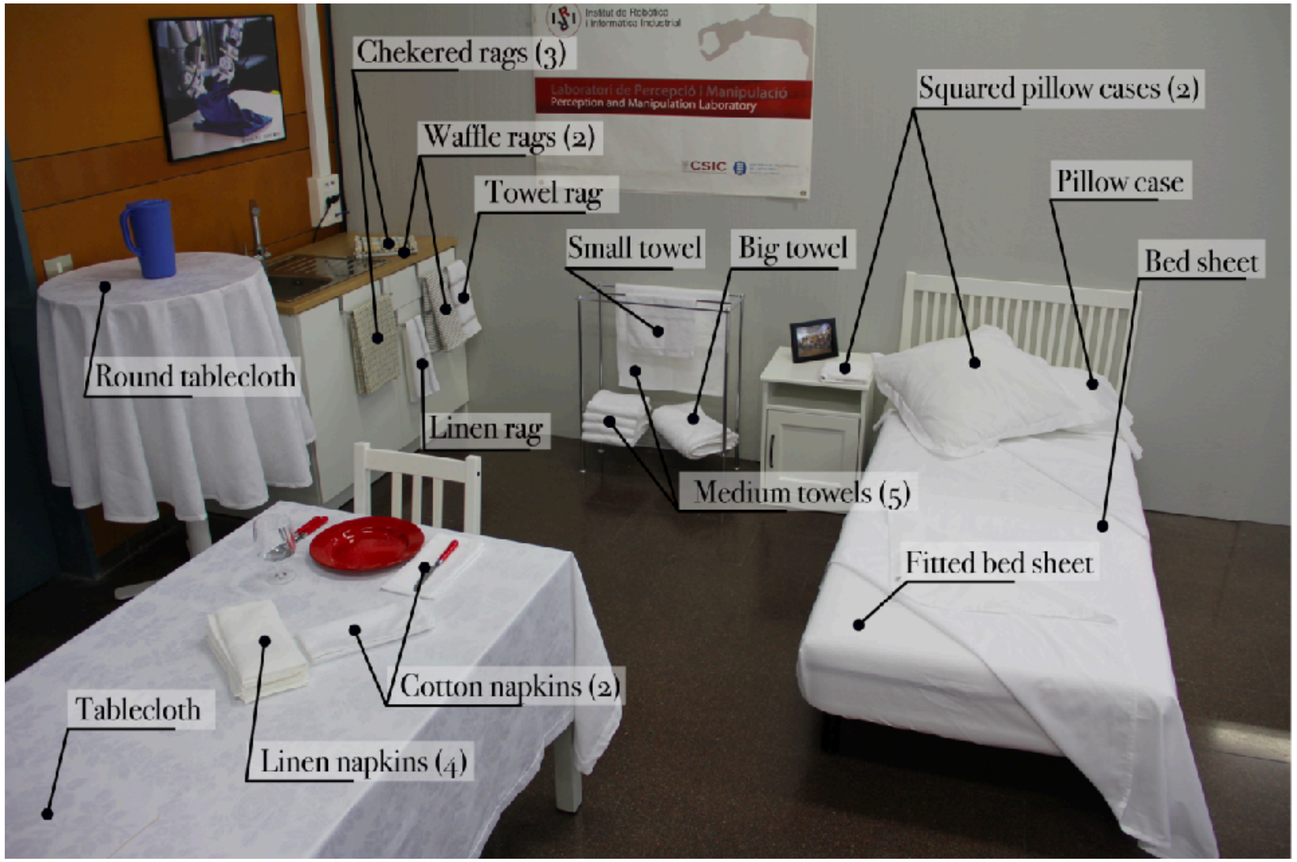
Amount of variation?

HOW CAN WE STANDARDIZE CLOTH OBJECT SETS FOR ENABLING COMPARISON?

MANIPULATION OBJECT SETS

YCB Object Set

Household Cloth Object Set



Rigid objects

Calli, et. al, 2015

Textile objects

Garcia-Camacho, et. al. 2022

TEXTILE CHARACTERIZATION

- Measurement systems CRITERIA:
  - General
  - Non-destructive
  - Easy-to-use
  - Repeatable

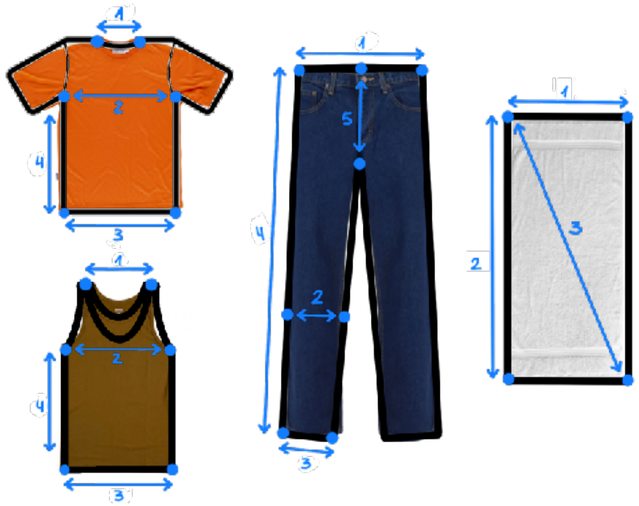
http://www.iri.upc.edu/groups/perception/#ClothStandardization

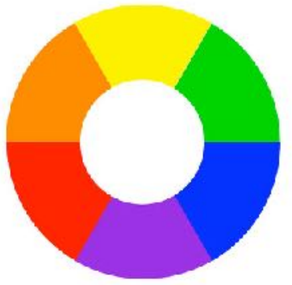
- Physical and mechanical properties

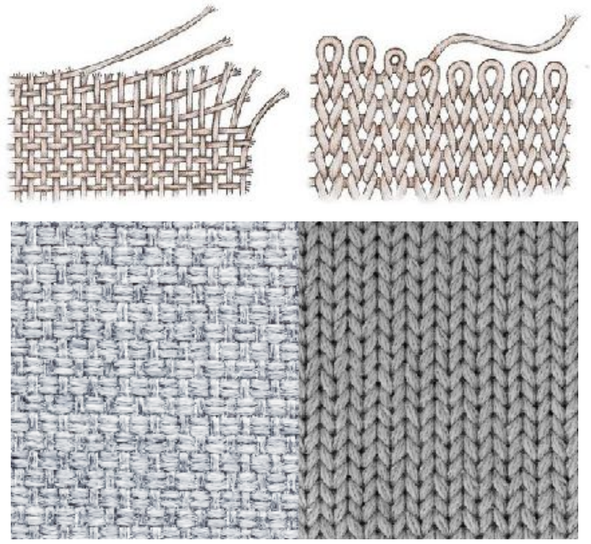
I. Garcia-Camacho, A. Longhini, M. Welle, G. Alenyà, D.. Kragic and J. Borràs, "**Standardization of cloth objects and its relevance in robotic manipulation**", 2024 IEEE International Conference on Robotics and Automation (ICRA)

TEXTILE CHARACTERIZATION

- Physical properties:
  - Shape
  - Size
  - Weight
  - Color
  - Fabric material
  - Construction technique

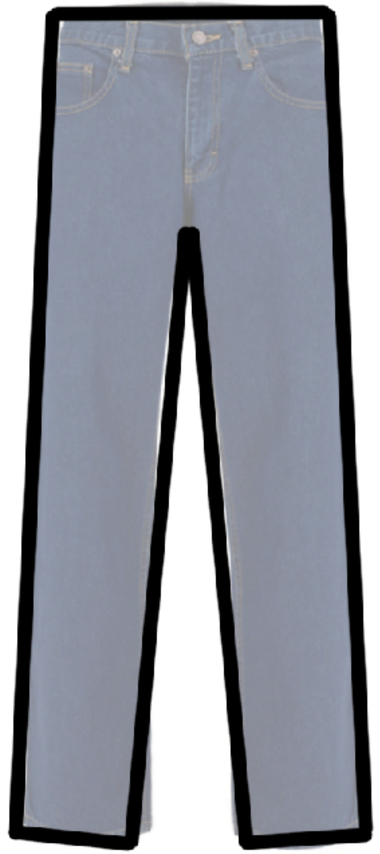


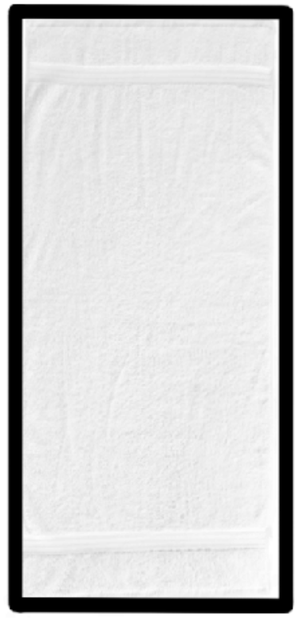




TEXTILE CHARACTERIZATION

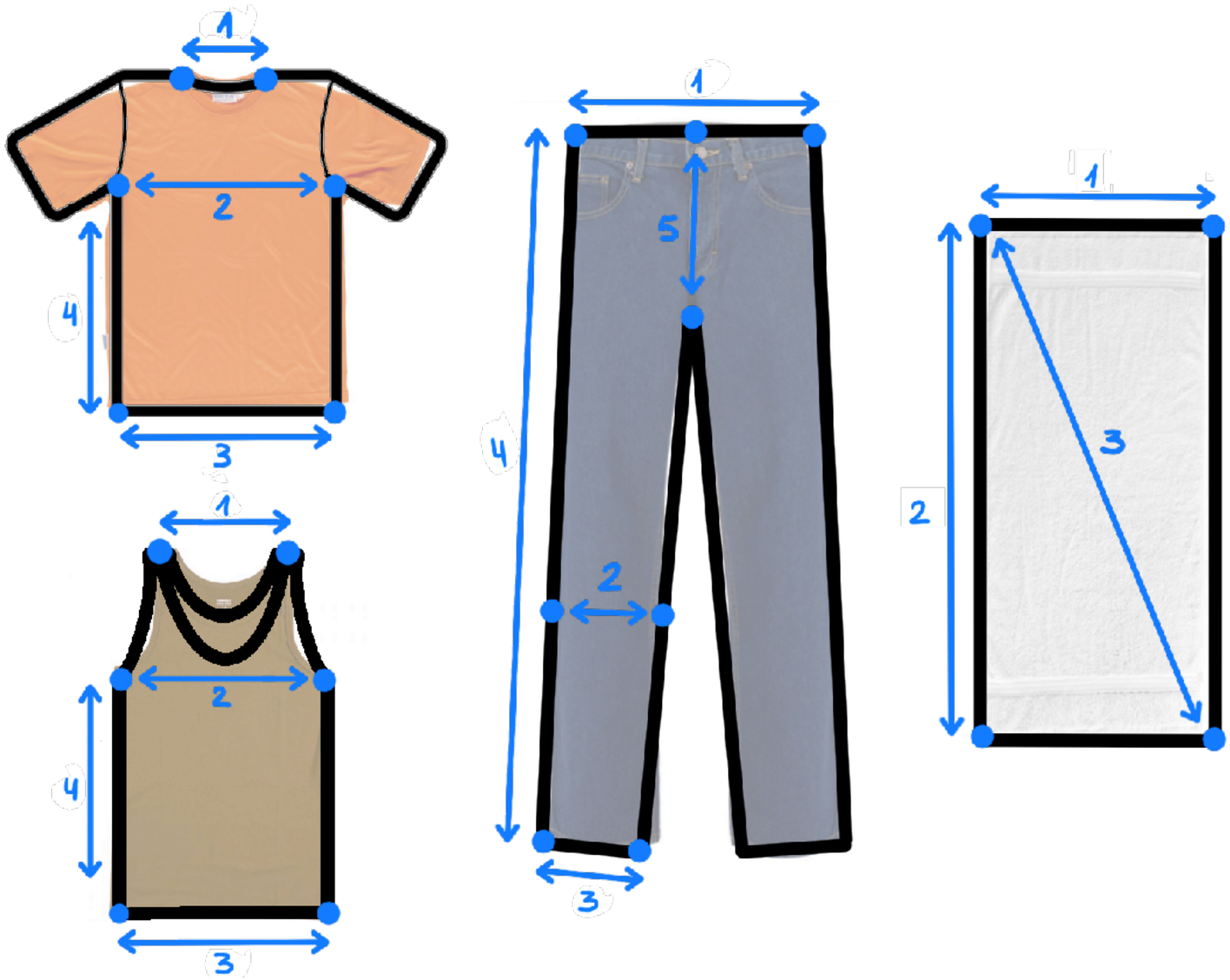
- Physical properties:
  - Shape





TEXTILE CHARACTERIZATION

- Physical properties:
  - Shape
  - Size

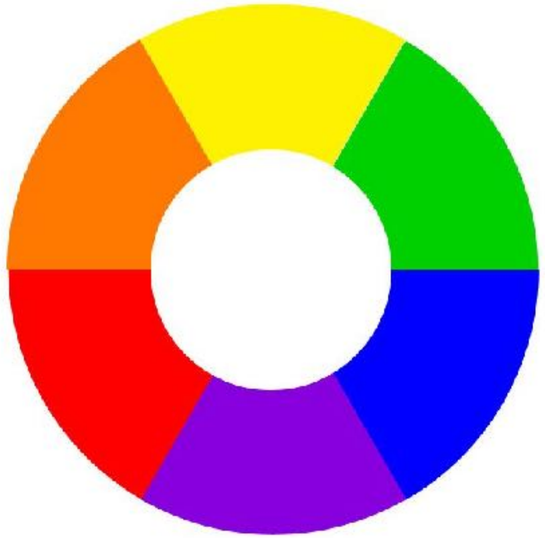


TEXTILE CHARACTERIZATION

- Physical properties:
  - Shape
  - Size
  - Weight

TEXTILE CHARACTERIZATION – PHYSICAL PROPERTIES

- Physical properties:
  - Shape
  - Size
  - Weight
  - Color

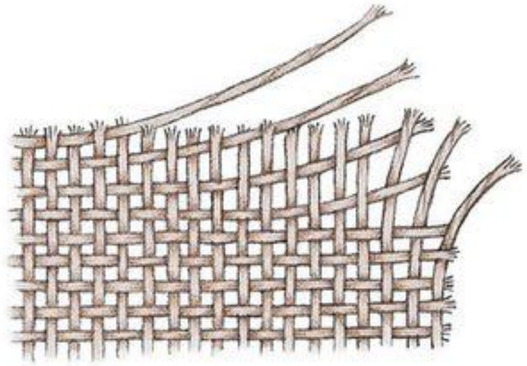


TEXTILE CHARACTERIZATION – PHYSICAL PROPERTIES

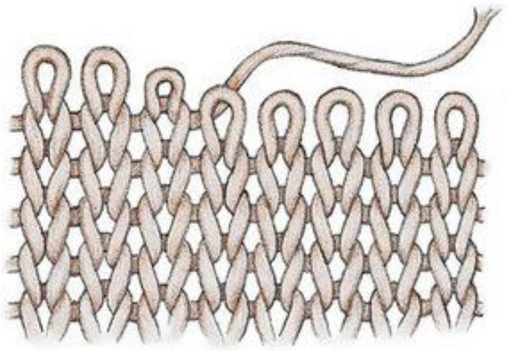
- Physical properties:
  - Shape
  - Size
  - Weight
  - Color
  - Fabric material

TEXTILE CHARACTERIZATION – PHYSICAL PROPERTIES

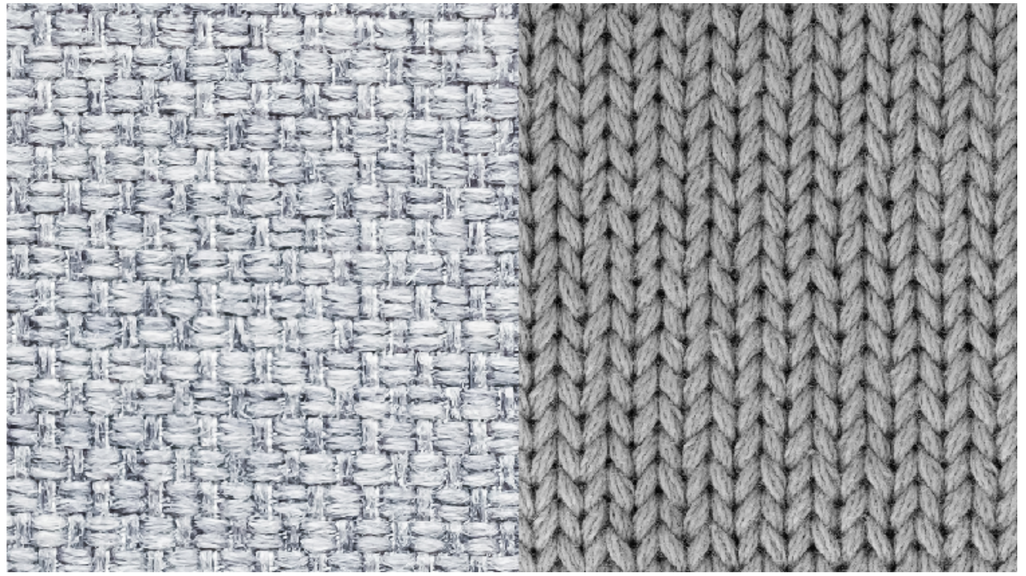
- Physical properties:
  - Shape
  - Size
  - Weight
  - Color
  - Fabric material
  - Construction technique



Woven yarn



Knitted yarn



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- Mechanical properties:
  - Stiffness

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

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TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

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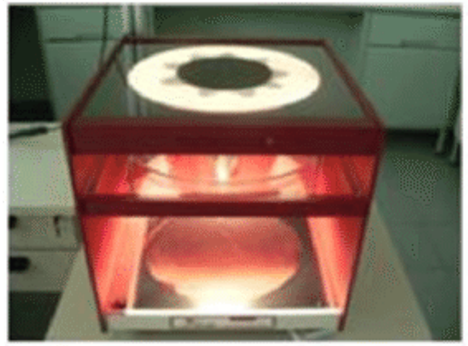
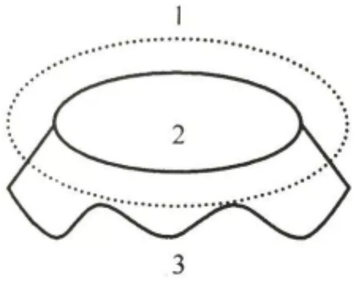
Textile industry

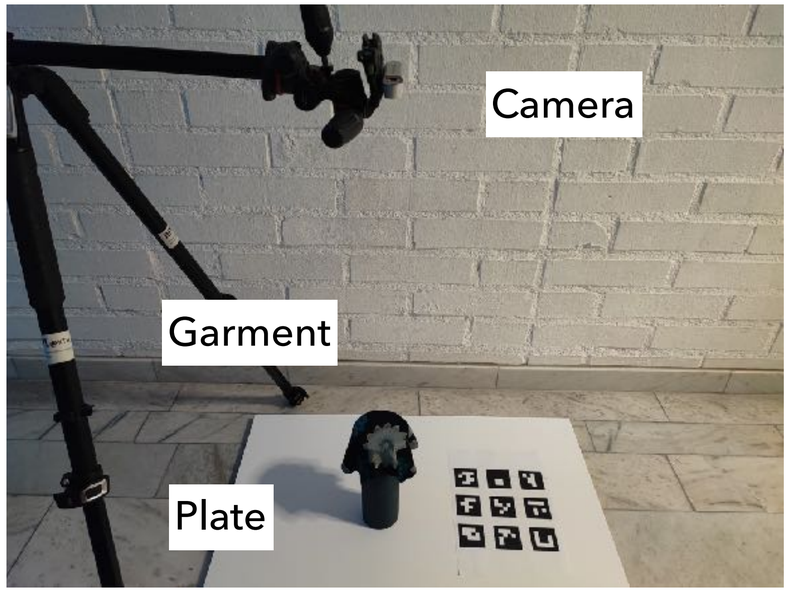


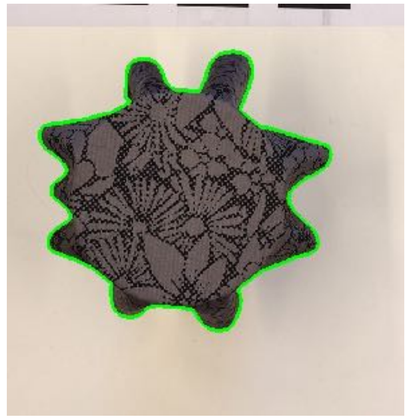


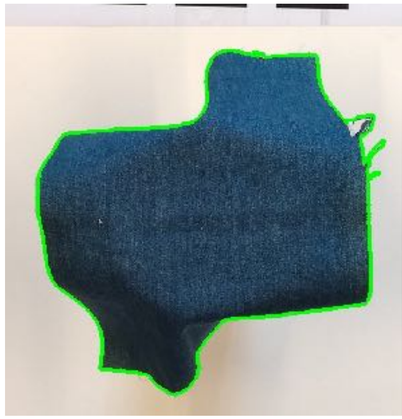
Cusick et. al. 1968

$$stiffness = \frac{A_3 - A_2}{A_1 - A_2}$$

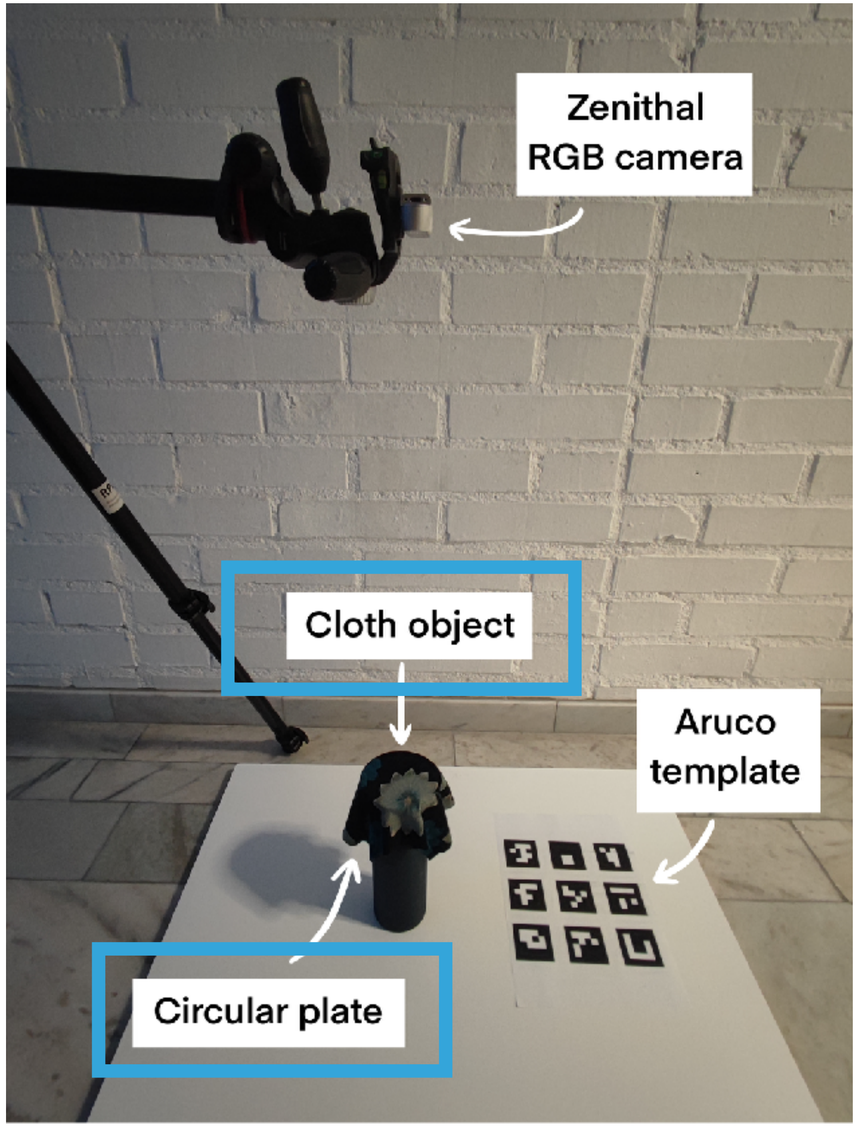
Proposed method



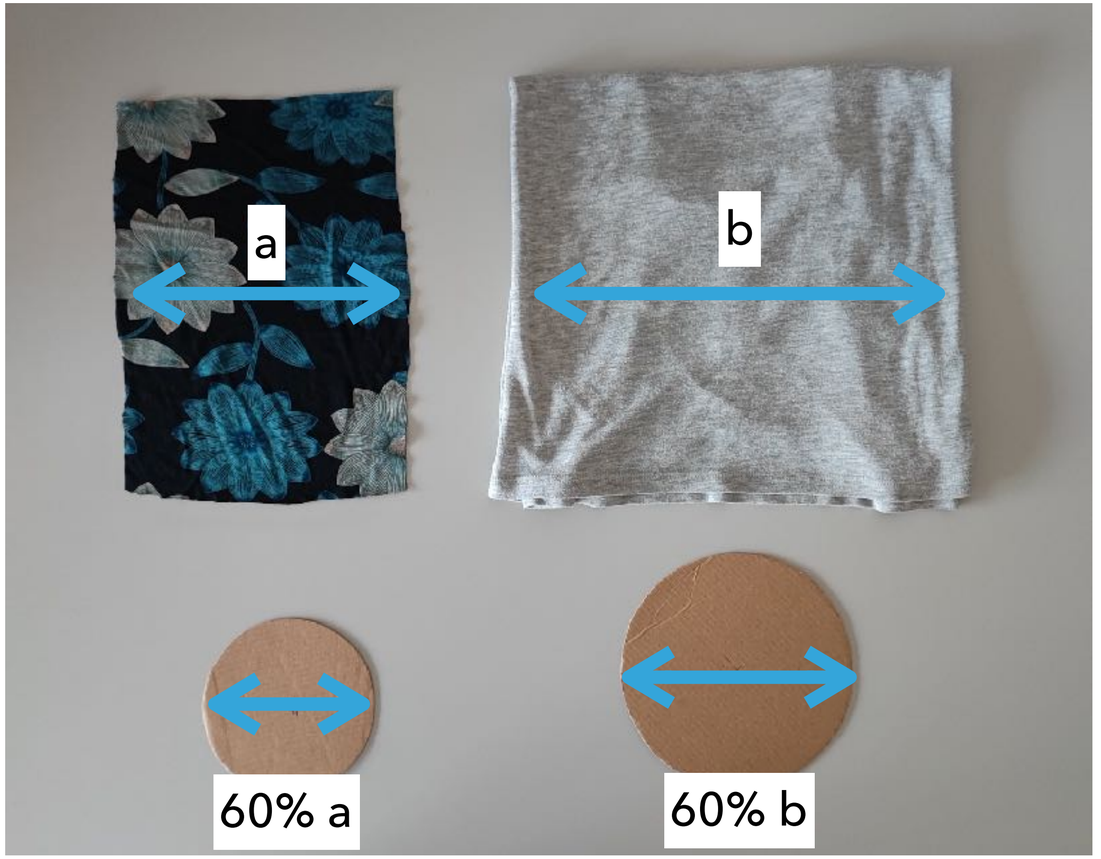




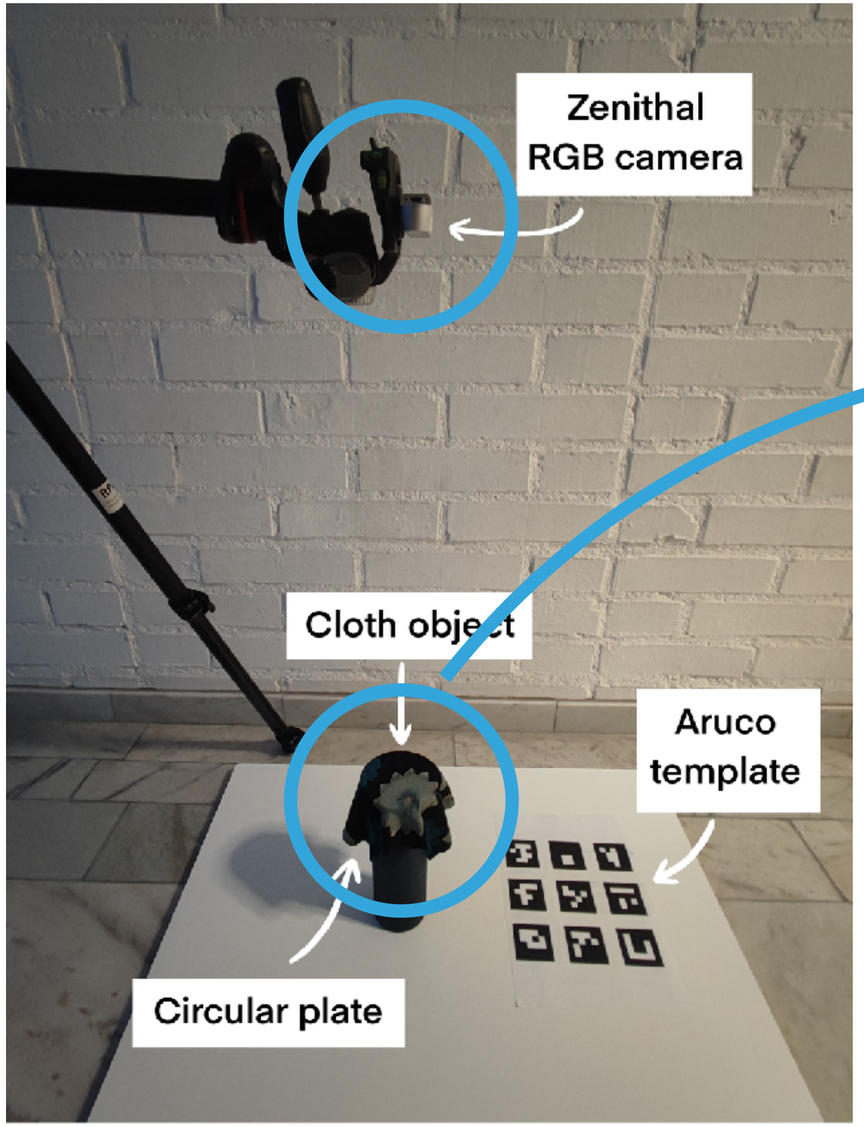
TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES



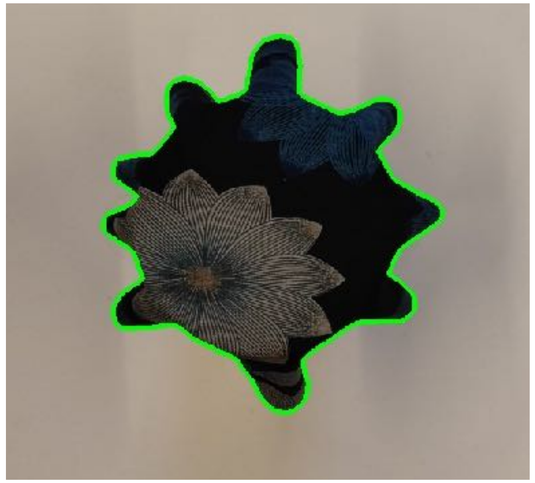
STIFFNESS



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES



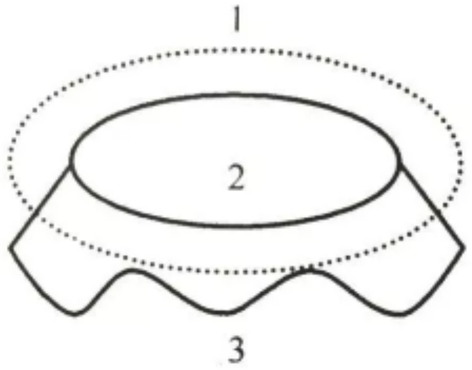
STIFFNESS



GITHUB REPOSITORY

AVAILABLE!

https://github.com/igarcica/TextileCharacterization



$$stiffness = \frac{A_3 - A_2}{A_1 - A_2}$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- Mechanical properties:
  - Stiffness
  - Friction
  - Elasticity

Textile industry

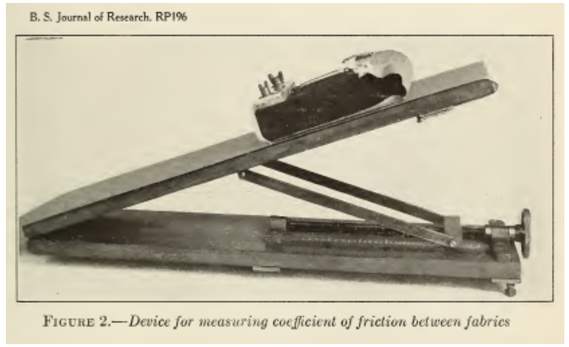
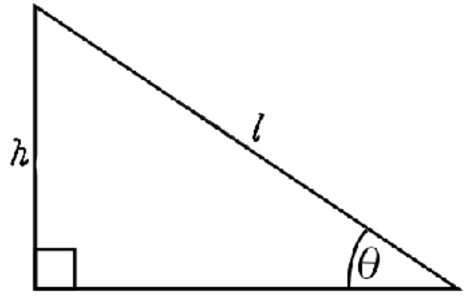
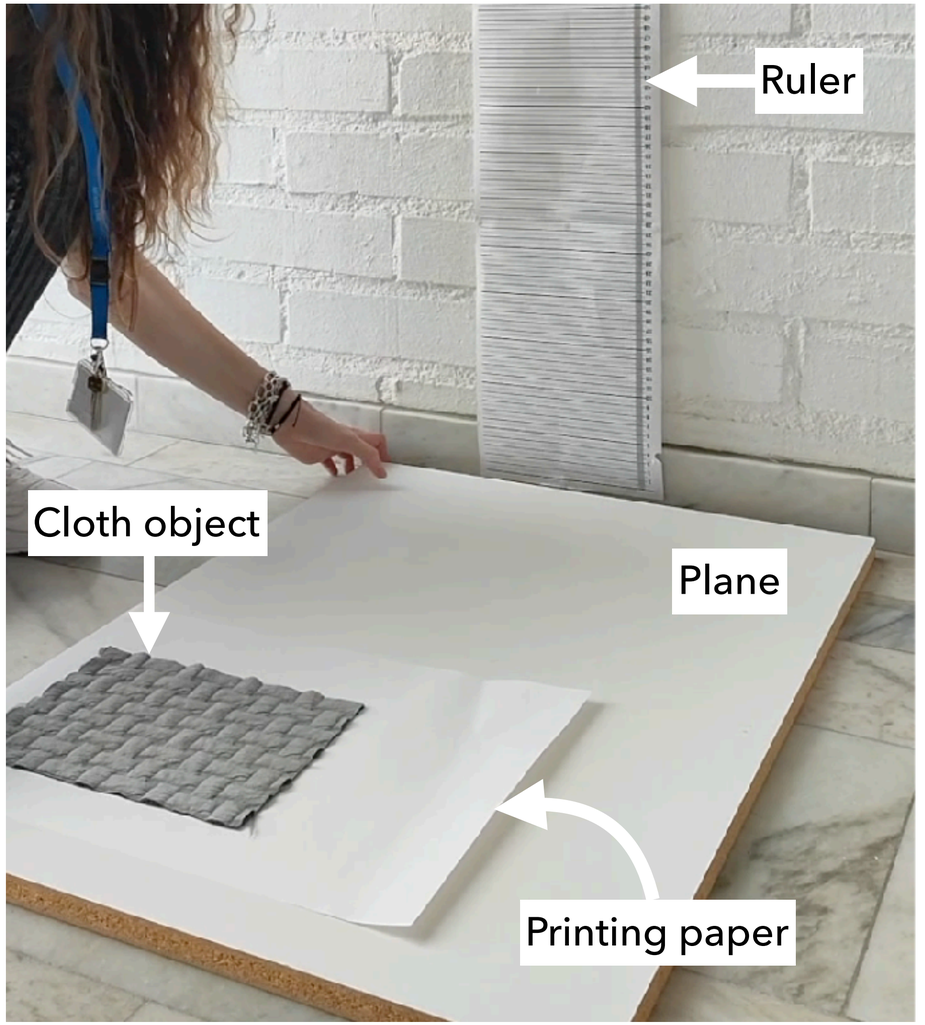

B. S. Journal of Research, RP196

FIGURE 2.—*Device for measuring coefficient of friction between fabrics*



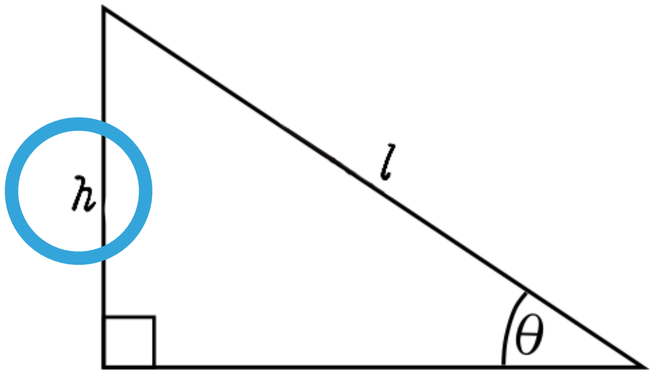
Mercier et. al. 1930

$$friction = \mu = tan\left(sin^{-1}\left(\frac{h}{l}\right)\right)$$



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

FRICTION

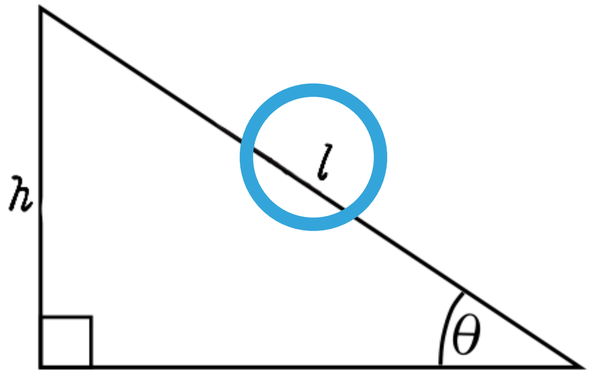


$$\theta = sin^{-1}(\frac{h}{l})$$

$$\mathbf{F}_f = \mathbf{F}_g$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

FRICTION

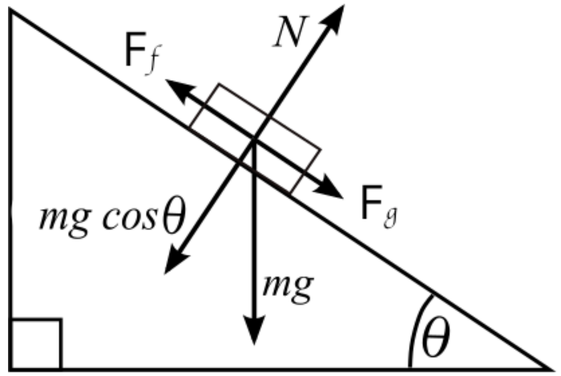


$$\theta = sin^{-1}(\frac{h}{l})$$

$$\mathbf{F}_f = \mathbf{F}_g$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

FRICTION



$$\theta = sin^{-1}(\frac{h}{l})$$

$$\mathbf{F}_f = \mathbf{F}_g$$

$$F_f = \mu N = \mu m g cos(\theta)$$

$$F_g = m g sin(\theta)$$

$$friction = \mu = tan\left(sin^{-1}\left(\frac{h}{l}\right)\right)$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- Mechanical properties:
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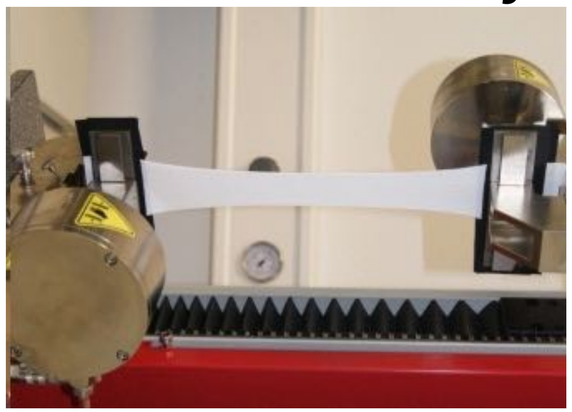
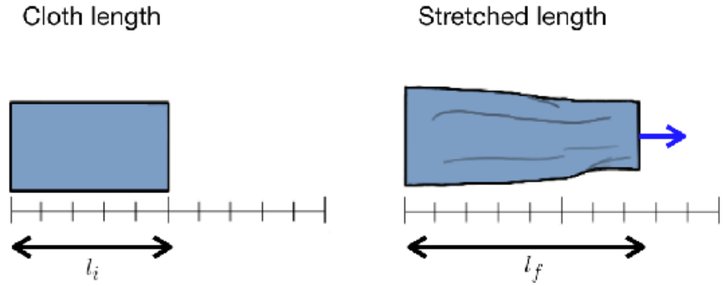
Textile industry

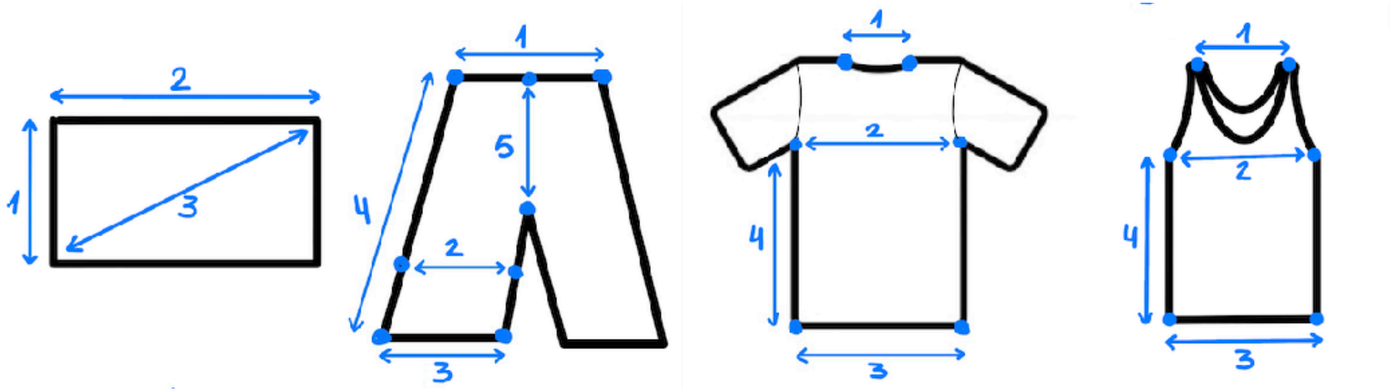


ASTM D76/D76M-21

$$elasticity = \frac{l_f - l_i}{l_i}$$

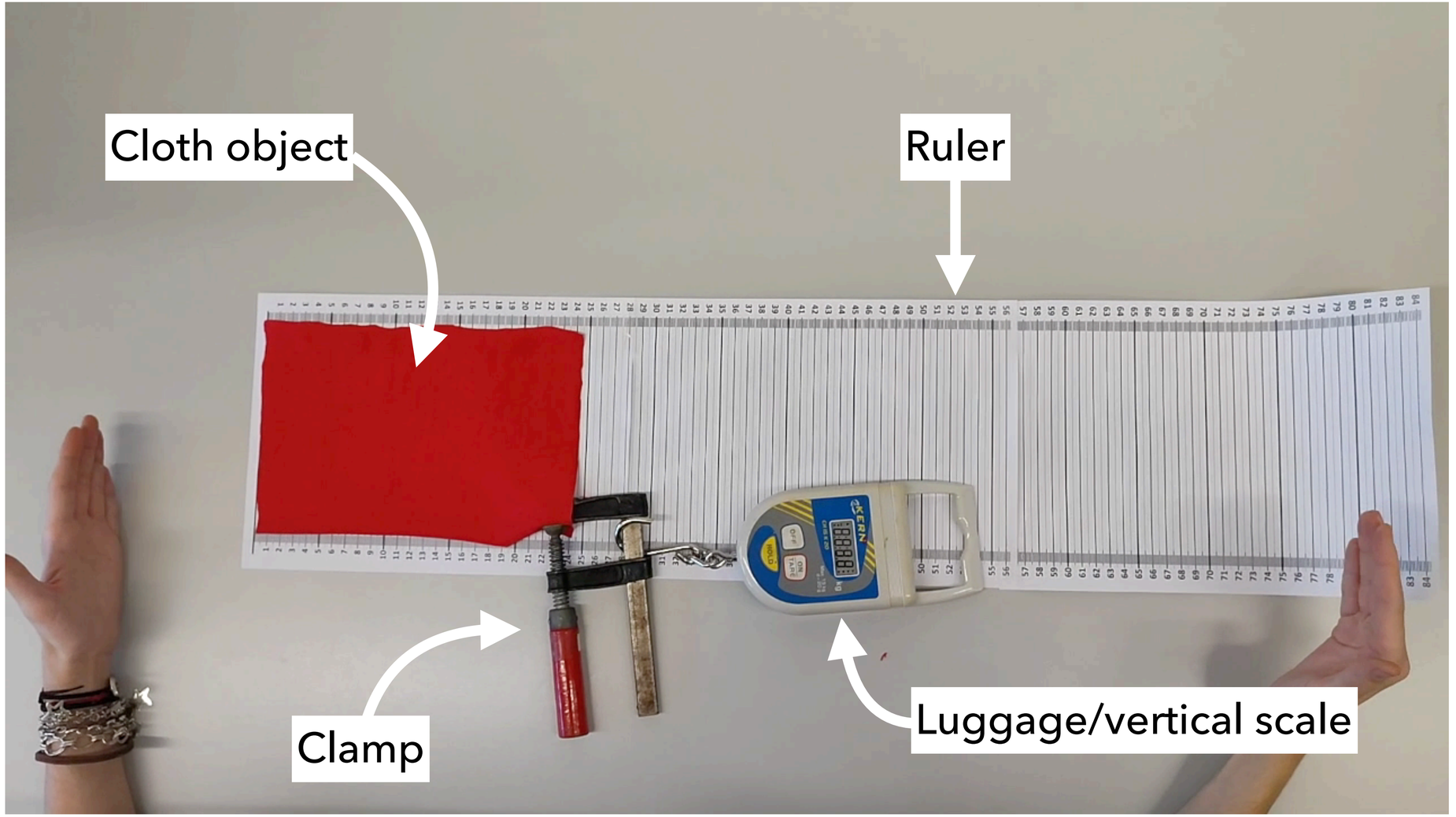
Proposed method





TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

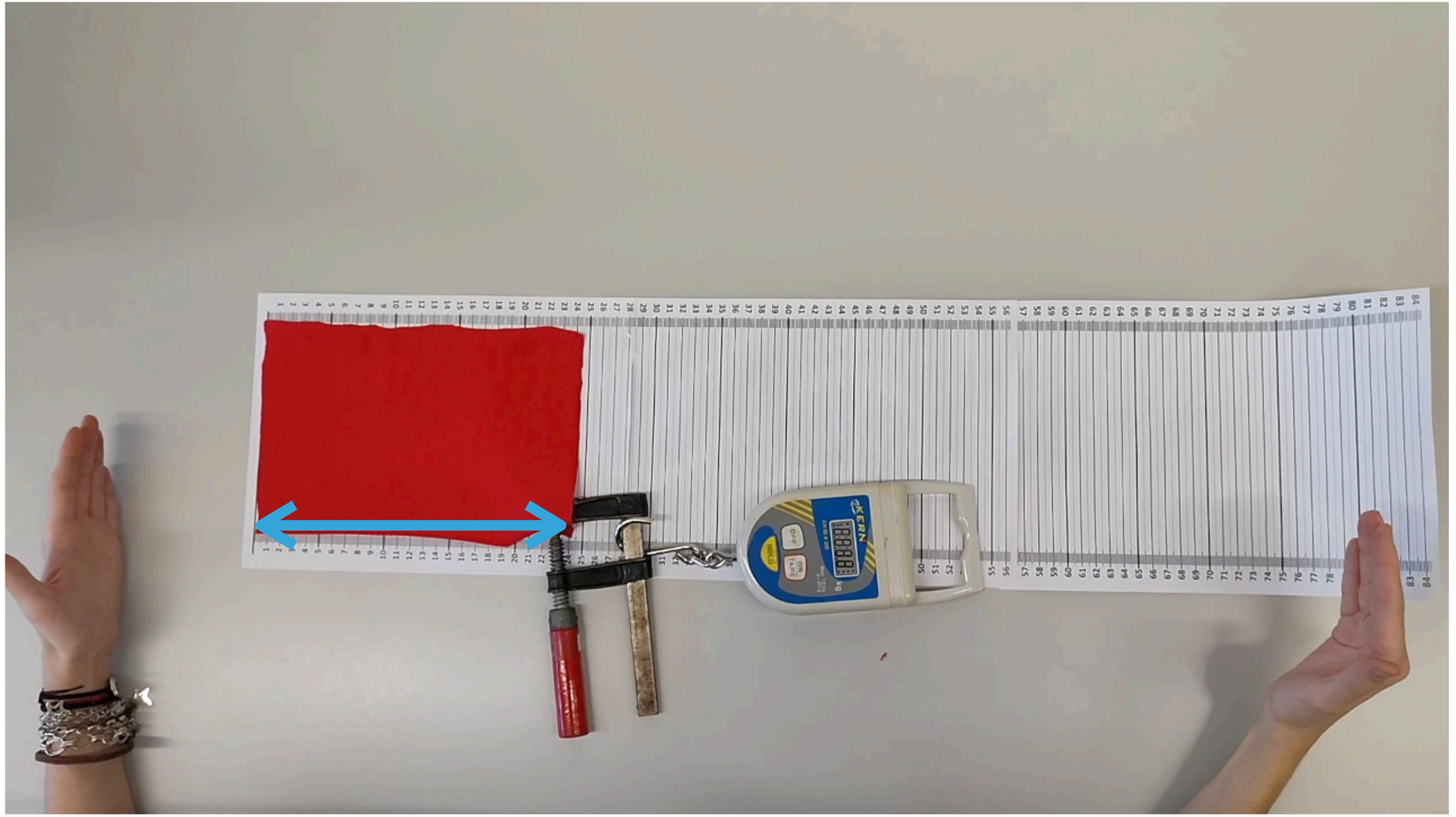
ELASTICITY



$$elasticity = \frac{l_f - l_i}{l_i}$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

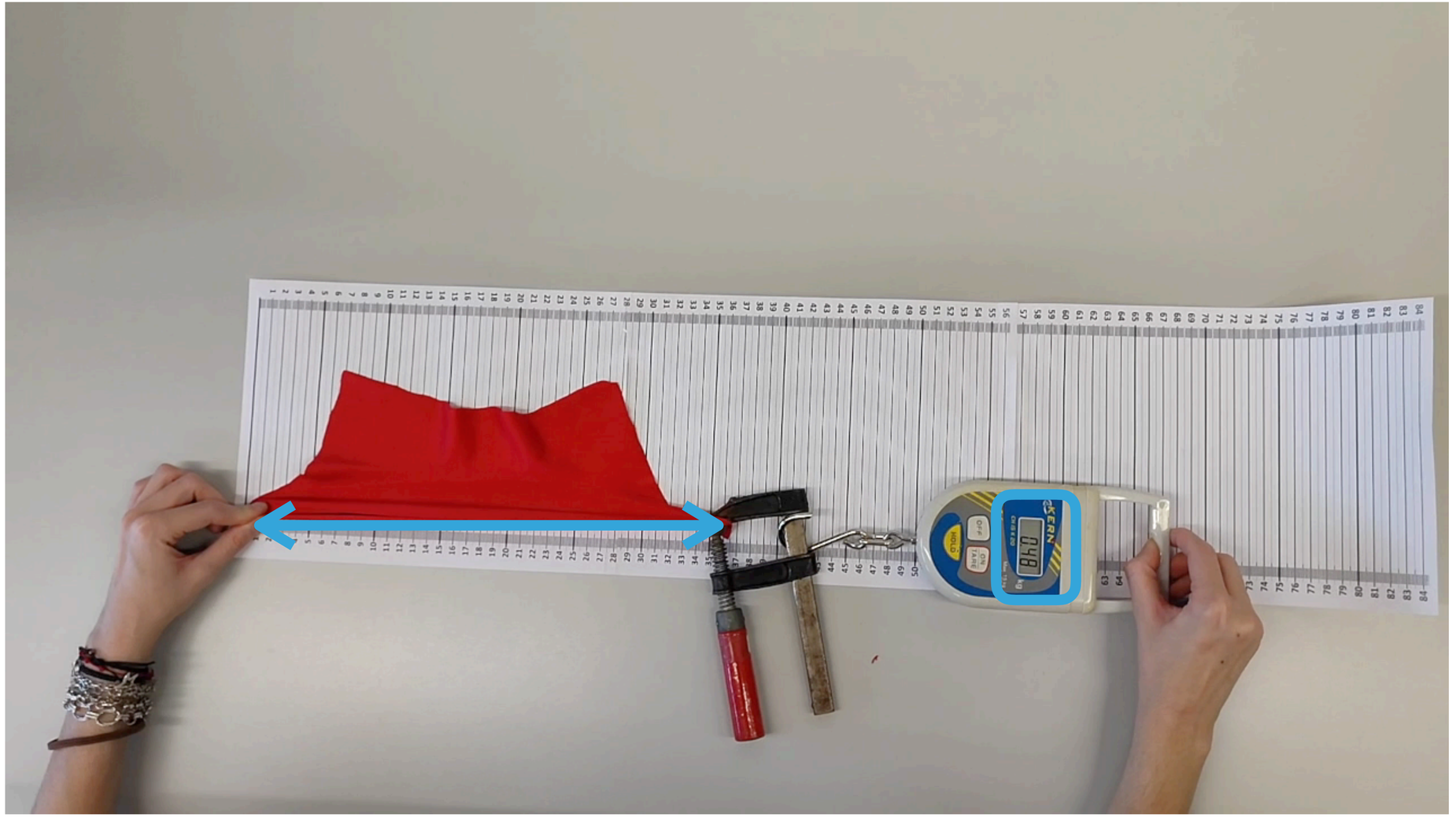
ELASTICITY



$$elasticity = \frac{l_f - l_i}{l_i}$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

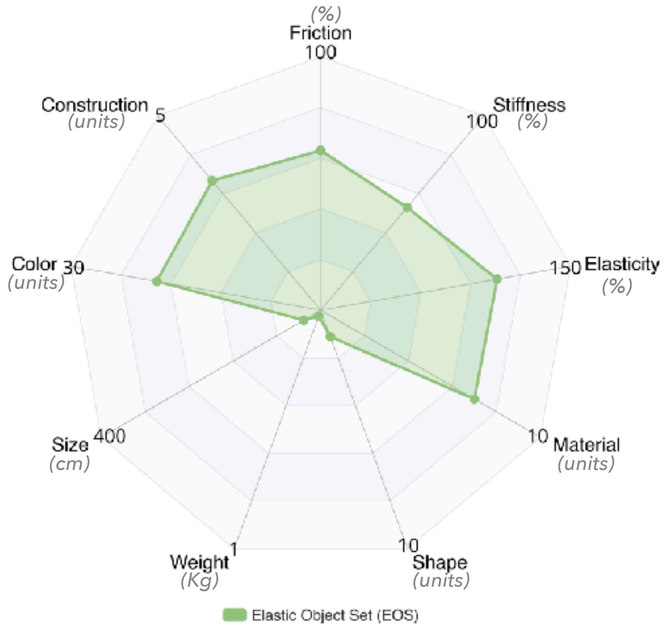
ELASTICITY



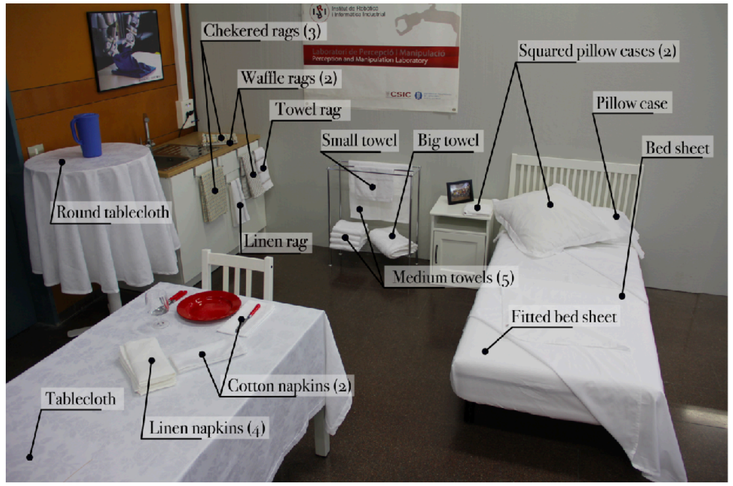
$$elasticity = \frac{l_f - l_i}{l_i}$$

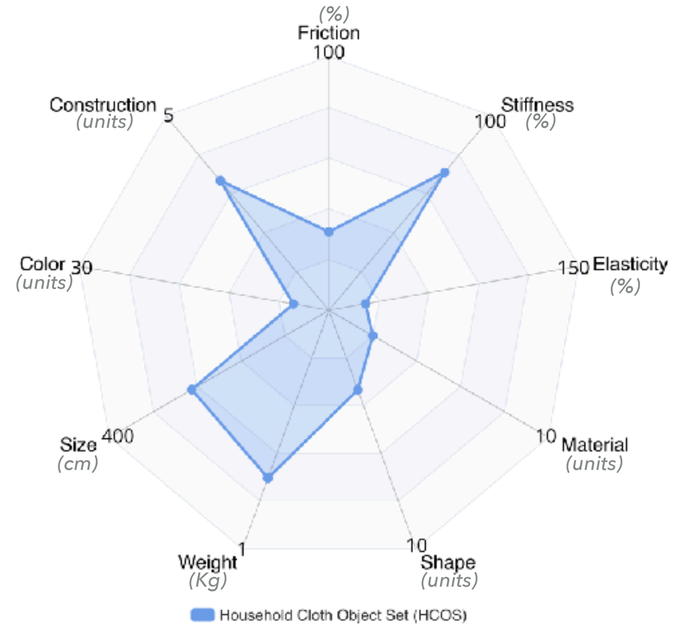
BENCHMARKING CLOTH SETS

EOS (Longhini et. al. 2023)

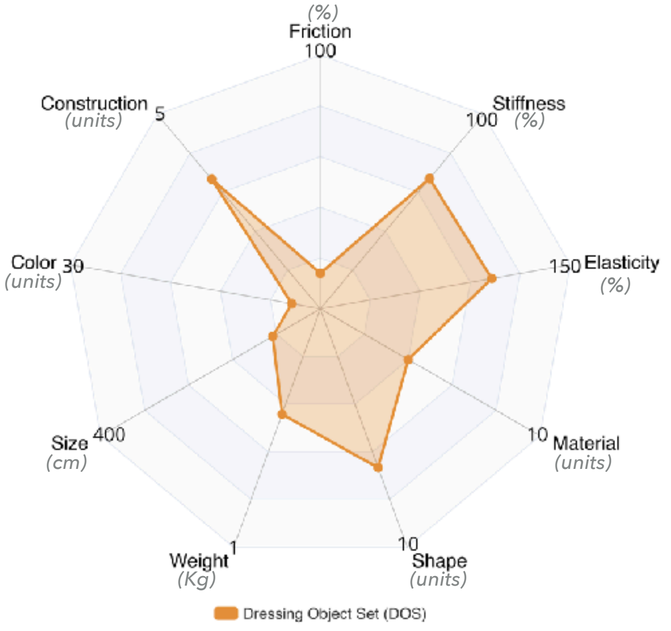


HCOS (Garcia-Camacho et. al. 2022)





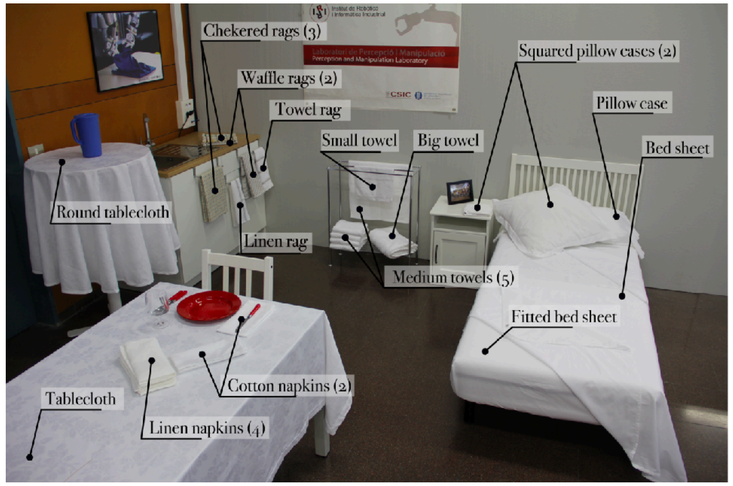
DOS (Gustavsson et. al. 2022)



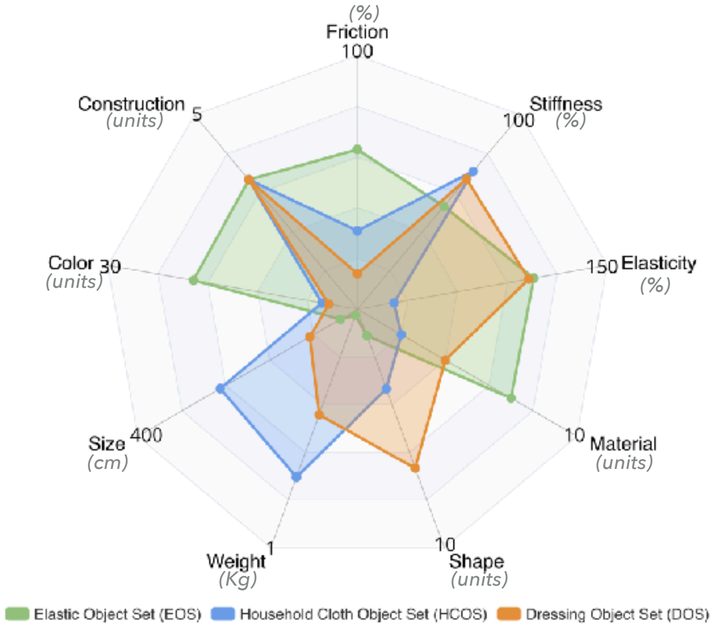
BENCHMARKING CLOTH SETS

EOS (Longhini et. al. 2023)

HCOS (Garcia-Camacho et. al. 2022)

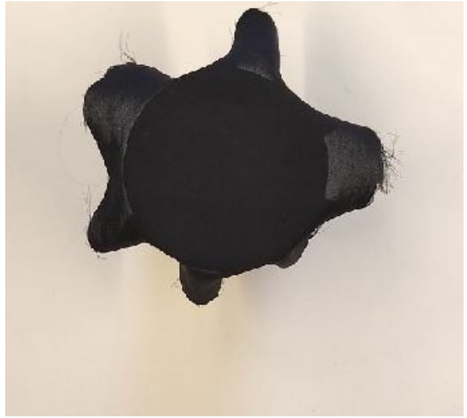


DOS (Gustavsson et. al. 2022)



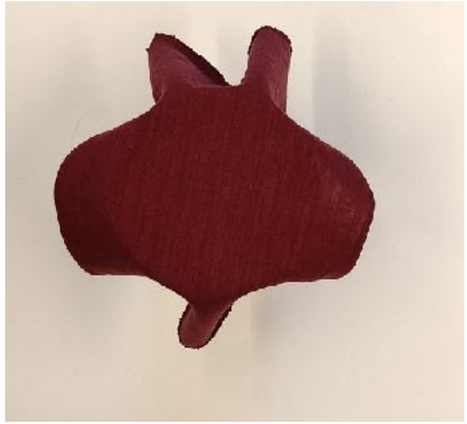
RELEVANCE OF CLOTH PROPERTIES IN ROBOTIC MANIPULATION

Sample A
Green wool knitted



Sample B
Black polyester woven

Sample C
Red elastane knitted



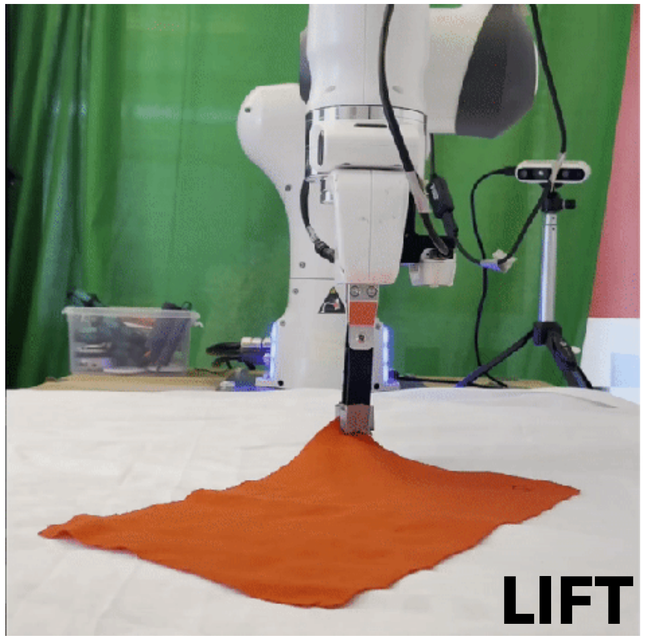
Sample D
Maroon

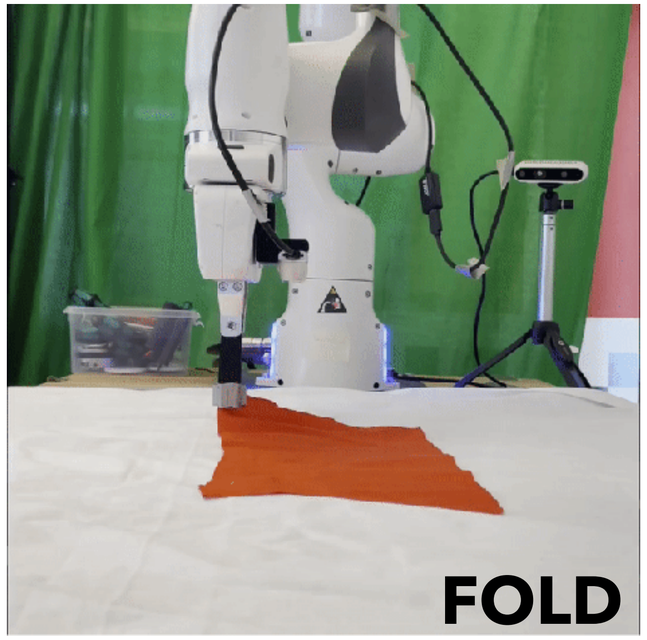
Sample F
Gray elastane woven

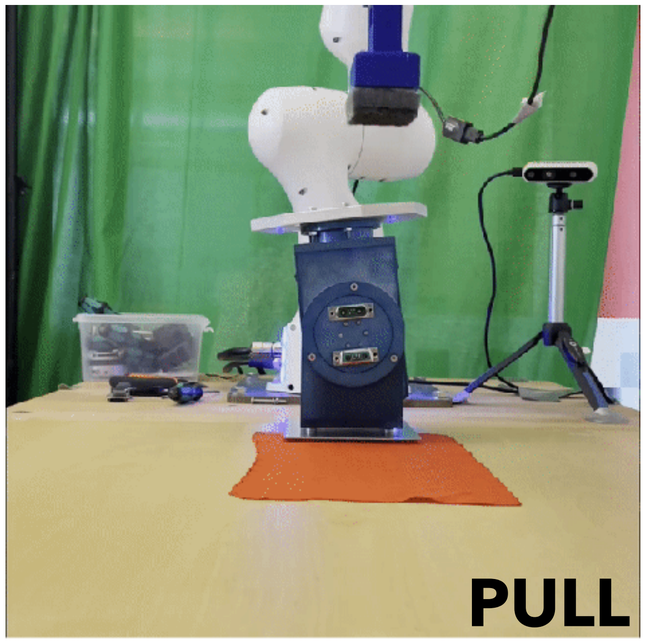
Sample	Stiffness	Elasticity	Friction
A	**85%**	43%	53%
B	34%	**7%**	**45%**
C	36%	87%	52%
D	39%	35%	**93%**
E	59%	**100%**	60%
F	**32%**	64%	52%

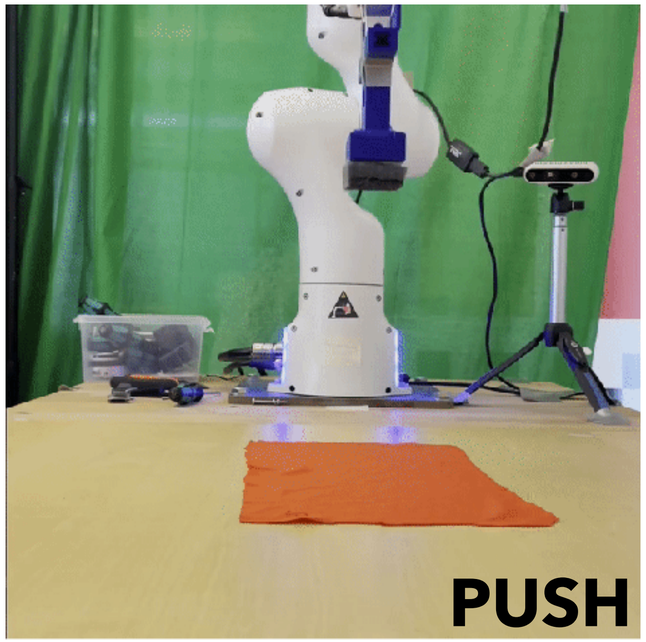
Sample E
Black&White

RELEVANCE OF CLOTH PROPERTIES IN ROBOTIC MANIPULATION



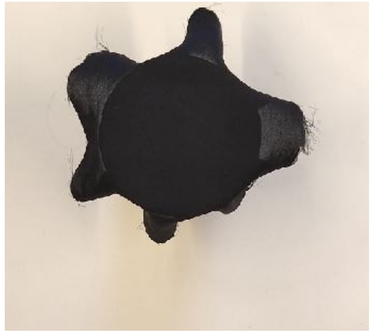






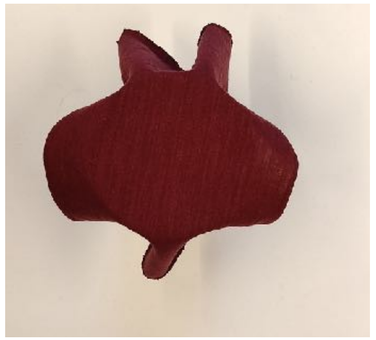
RELEVANCE OF CLOTH PROPERTIES IN ROBOTIC MANIPULATION

Sample A



Sample B

Sample C



Sample D

Sample E

Sample F

Sample	Stiffness	Elasticity	Friction	Lift	Drag	Fold	Pull	Push
A	**85%**	43%	53%	**0.31 ± 0.01**	**0.97 ± 0.01**	**1.00 ± 0.0**	0.94 ± 0.02	0.83 ± 0.00
B	34%	**7%**	**45%**	0.23 ± 0.00	0.96 ± 0.02	0.63 ± 0.01	**0.97 ± 0.00**	**0.84 ± 0.01**
C	36%	87%	52%	0.23 ± 0.02	0.90 ± 0.01	0.63 ± 0.00	0.72 ± 0.07	0.64 ± 0.03
D	39%	35%	**93%**	0.20 ± 0.00	0.84 ± 0.02	0.63 ± 0.01	0.90 ± 0.03	0.69 ± 0.05
E	59%	**100%**	60%	0.21 ± 0.01	0.93 ± 0.00	0.60 ± 0.02	0.91 ± 0.01	0.65 ± 0.02
F	**32%**	64%	52%	0.20 ± 0.00	0.79 ± 0.03	0.60 ± 0.00	0.88 ± 0.02	0.66 ± 0.02

HANDS ON – MINI PROJECT SESSION

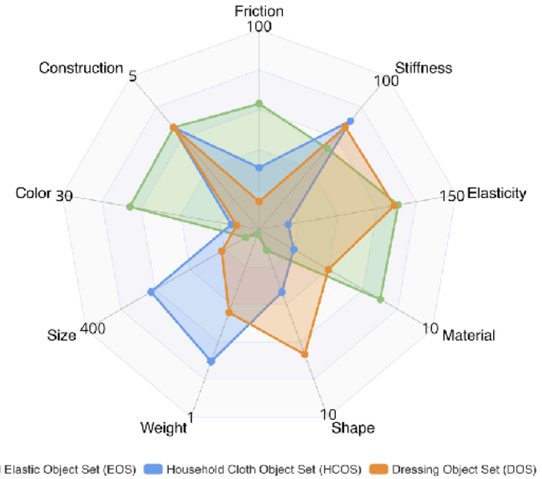
Object sets

Textile characterization

Table

Object	Image	Size sh…	Size long	Size (di…	Area	Weight…	Weight…	Shape	Colors	Textures	Material
Black flowers		17	23	29	391	8.4	0.0084	Rectang…	Black, Whit…	Texture1	Polyester, Elastane
Black		17	30	34	510	6	0.006	Rectang…	Black	Black	Polyester
Denim		17	25	30	425	11.45	0.01145	Rectang…	Blue	Blue	Cotton
Brown		20	22	30	440	16.85	0.01685	Rectang…	Brown	Brown	Wool
Green wool		16	28	32	448	23.1	0.0231	Rectang…	Green	Green	Wool
Black wool		17	31	35	527	16.4	0.0164	Rectang…	Black	Black	Wool
Black & white		18	25	31	450	13.74	0.01374	Rectang…	Black, Whit…	Texture2	Acrylic
Brownish		17	32	38	544	17.6	0.0176	Rectang…	White, Blacl…	Texture3	Wool
White thin		14.5	31	34	449.5	14.5	0.0145	Rectang…	White	White	Wool
Dark blue thick v…		14	26	30	364	18.4	0.0184	Rectang…	Blue	Blue	Wool
White thick knit		19	32	37	608	26.5	0.0265	Rectang…	White	White	Acrylic
Dark blue thin		16	24	29	384	15	0.015	Rectang…	Blue	Blue	Wool
Red		17	30	34	510	6.85	0.00685	Rectang…	Red	Red	Elastane, Polyester
Flowers gray		18	30	35	540	9.6	0.0096	Rectang…	Black, Gray	Texture4	Elastane
		NOT EMPTY 37				AVERAGE 17.18	AVERAGE 26.97	MAX 37	AVERAGE 10.82	UNIQUE 1	UNIQUE 10	UNIQUE 23	UNIQUE 7

Radar chart



Study impact in manipulation

ROMANDIC

SCAN ME!

BENCHMARKING CLOTH MANIPULATION: ENABLING COMPARISON THROUGH STANDARDIZATION

IRENE GARCIA-CAMACHO

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Institut de Robòtica i Informàtica Industrial