Autonomous Unfolding of Garments

Sotiris Malassiotis

CERTH

SEVENTH FRAMEWORK PROGRAMME

INFORMATICS & TELEMATICS INSTITUTE
centre for research and technology - hellas

Challenges of Garment Manipulation

- Equivalent to pick-and-place operations for rigid objects, but …
- Configuration i.e. 3D geometry changes continuously
- Predicting geometry (e.g. physics simulation) very challenging
- Tracking/discriminating configuration from images even more challenging
- Not strange than humans master this after the age of 3 years.

Challenges of Garment Manipulation

Garment Manipulation: Applications

- Home robotics:
  - Making the beds
  - Doing laundry
  - Dressing the kids…
- Garment Manufacturing
  - Towards full automation of the factory
- Manufacturing of 2D limp materials
  - Composite Materials
  - Medical textiles

Garment Manipulation: State-of-the-art

- Simplify the problem … make it 2D
- … with help of gravity and two grasp points …
- lowest point manipulation procedure
- find corners of towel
- cooperation between tactile/force and visual feedback: tracing a seam
- grasp from outline points.

Autonomous Unfolding using Random Forests & Probabilistic Planning

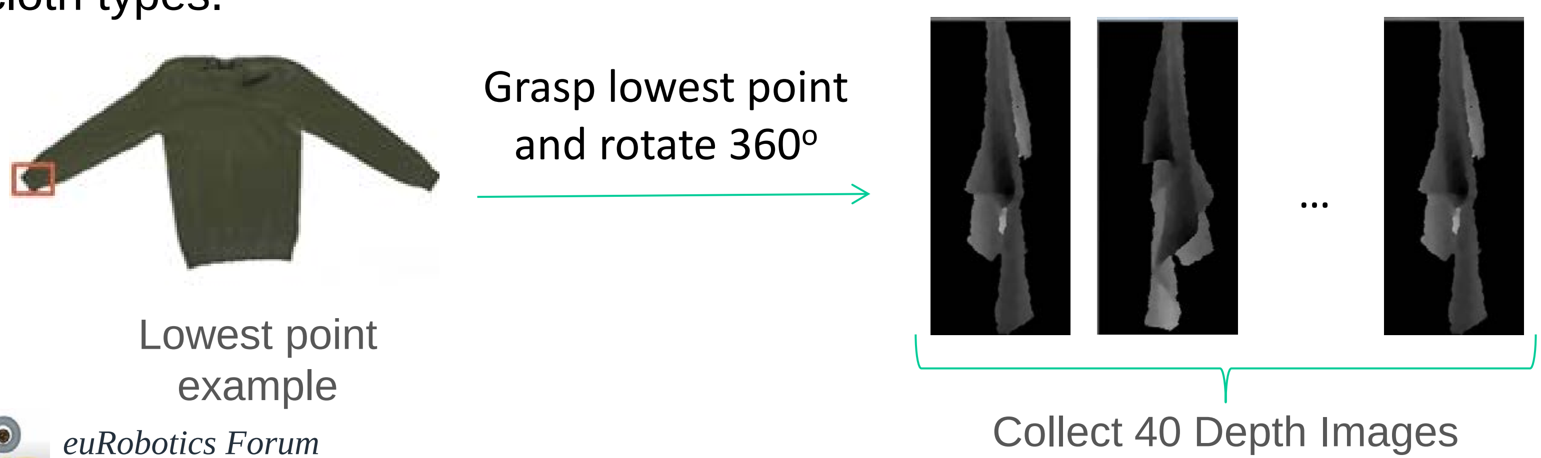
- Grasp two key-points that will allow the garment to naturally unfold due to gravity
- Machine learning for garment classification and key point detection
- Novelty:
  - Very fast
  - Does not need a supporting surface

Garment Recognition

- Grasp a cloth from a **random point**.
- While hanging, grasp **the lowest point**. Possible lowest points are limited.

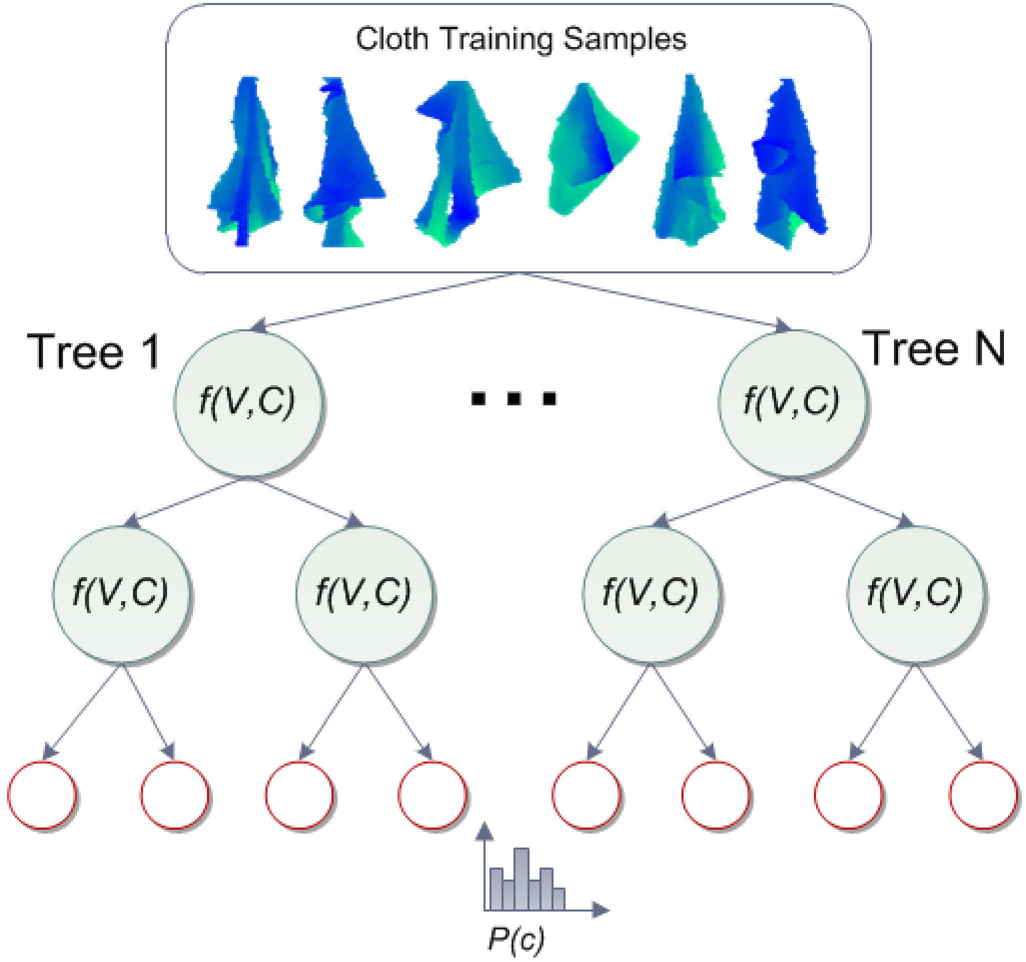
- Half points are **symmetric**. Each non-symmetric lowest point represents a **class**.

- **Training dataset :** Collect Depth Images for each non-symmetric lowest point for all cloth types.

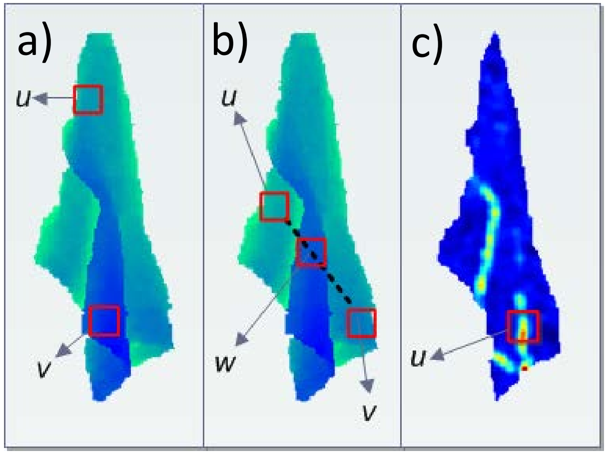


Clothes Recognition – Random Forests

Random Forests



Pixel Tests



Test at each node:

a) t = d(u) – d(v) > *t*

b) t = (d(u) – d(w)) – (d(w) – d(v)) > *t*

c) t = |Curv(u)| > *t*

u, v, w: Random positions

t: Best splitting threshold from random choices

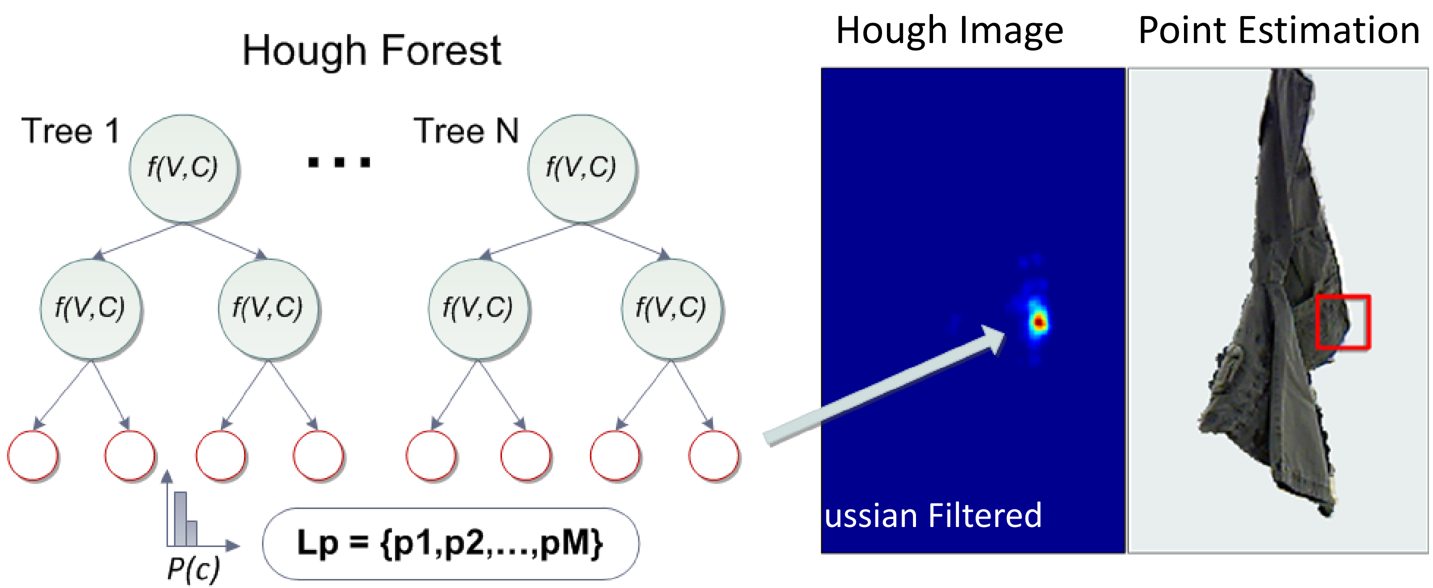
Hough Forests - Unfolding

- Detect the **two grasping point** which **unfolds** the cloth while hanging and **grasp** them.

Hough Forests - Estimating the position of the next grasping point

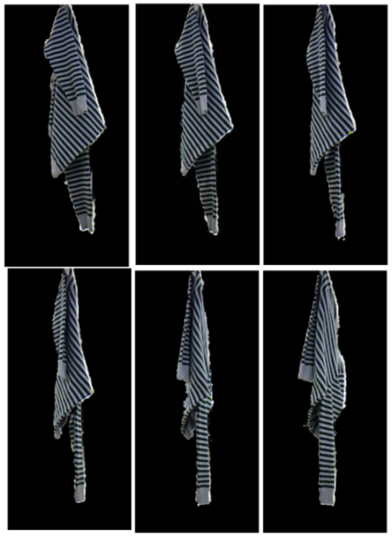
Classes

C1: GP invisible
C2: GP visible



Probabilistic Planning

- **One viewpoint** of the cloth is **not sufficient** for Recognition and Point Estimation.
- Cloth is **rotated** to capture more viewpoints
- We use Partially Observable Markov Decision Processes (**POMDPs)** in order to minimize the viewpoints needed to reach certain degree of confidence.



Cloth Viewpoints while Rotating

POMDP formulation

- **S** is the set of **states**.
- **A** is the set of **actions**.
- **O** is the set of **observations**.
- **T** is the conditional **transition probabilities**.
- **P** is the conditional **observation probabilities**.
- **R** is the **reward function** over the actions and states.
- **γ** is the **discount factor** of rewards over time.
- **b0** is the **initial belief state**.

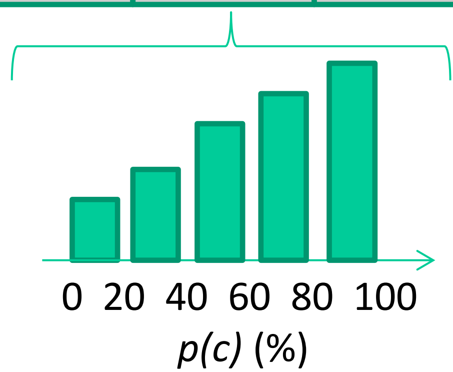
Interactive Recognition

States

Shirt	Trousers	Shorts 1	Shorts 2	TShirt1	TShirt2

Observations

Shirt	Trousers	Shorts 1	Shorts 2	TShirt1	TShirt2



=> 30 observations

Observation Probabilities

P(O | S) --- Measured Experimentally

Actions

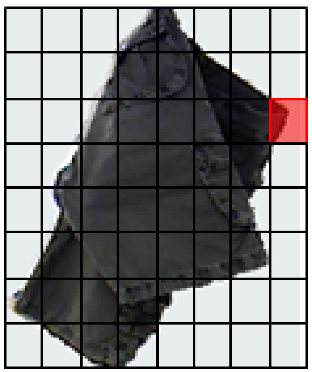
- Rotate Cloth
- Decide Shirt
- Decide Trousers
- Decide Shorts1
- Decide Shorts2
- Decide Tshirt1
- Decide Tshirt2

Rewards

- R > 0, Correct Decision
- R << 0, Wrong Decision
- R < 0 (small negative), Rotation

Interactive Point Estimation

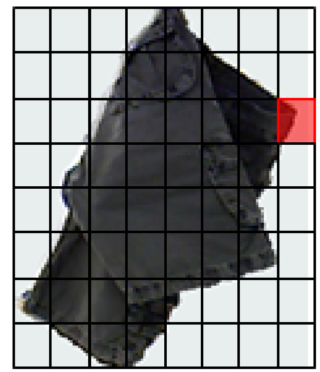
States

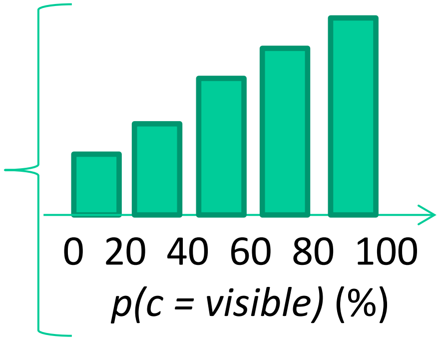


8x8 grid quantization

=> 64 states

Observations





=> 320 observations

Actions

- Rotate Cloth
- Grasp Location *i*, *i* = {1..64}

P(O | S) --- Measured Experimentally
T(S' | a, S) --- Measured Experimentally
b0 --- Measured Experimentally

Rewards

- R >> 0, Grasp Correct Location
- R << 0, Grasp Wrong Location
- R > 0, Rotate if GP is invisible
- R < 0, Rotate if GP is visible

Probabilistic Planning

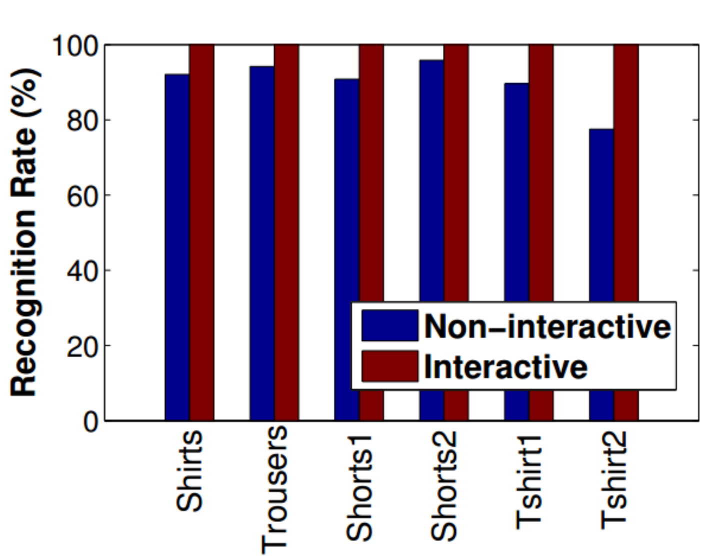
Belief update at each rotation:

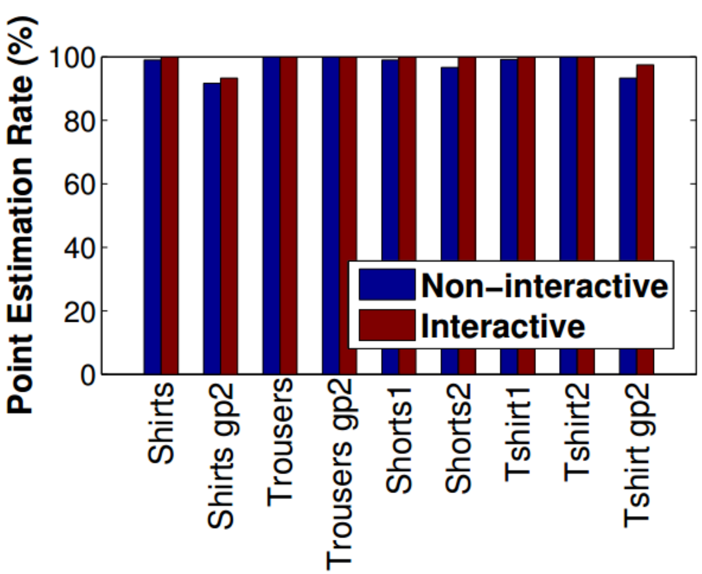
$$b'(s') = \frac{P(o|s',a)\sum_{s\in S} T(s'|s,a)b(s)}{\sum_{s'\in S} P(o|s',a)\sum_{s\in S} T(s'|s,a)b(s)}$$

POMDP solution:

A(b(**S**)),
A - optimal action policy

Results





Results

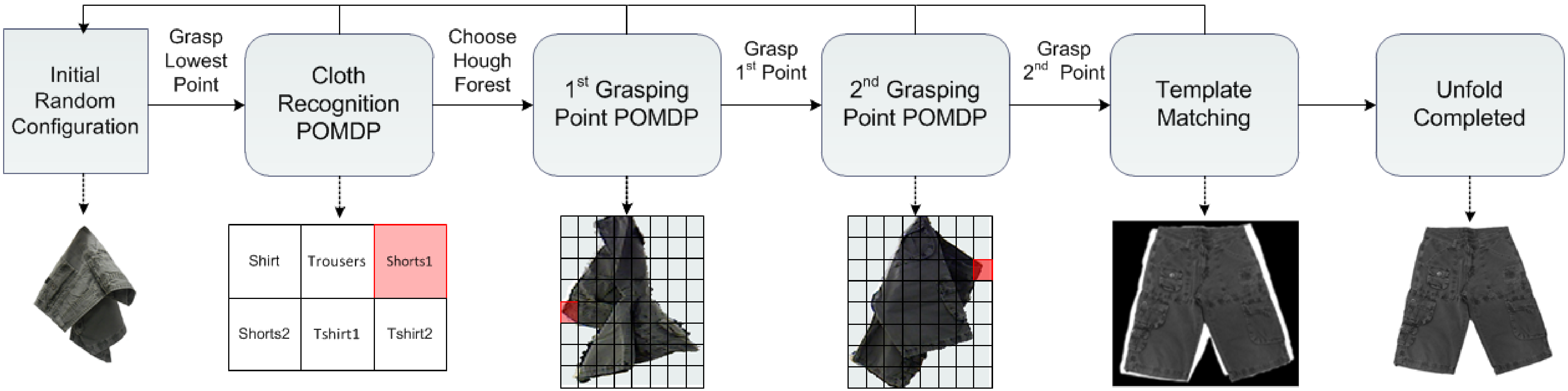
Positive examples

Negative examples

Grasping errors

Probabilistic Planning

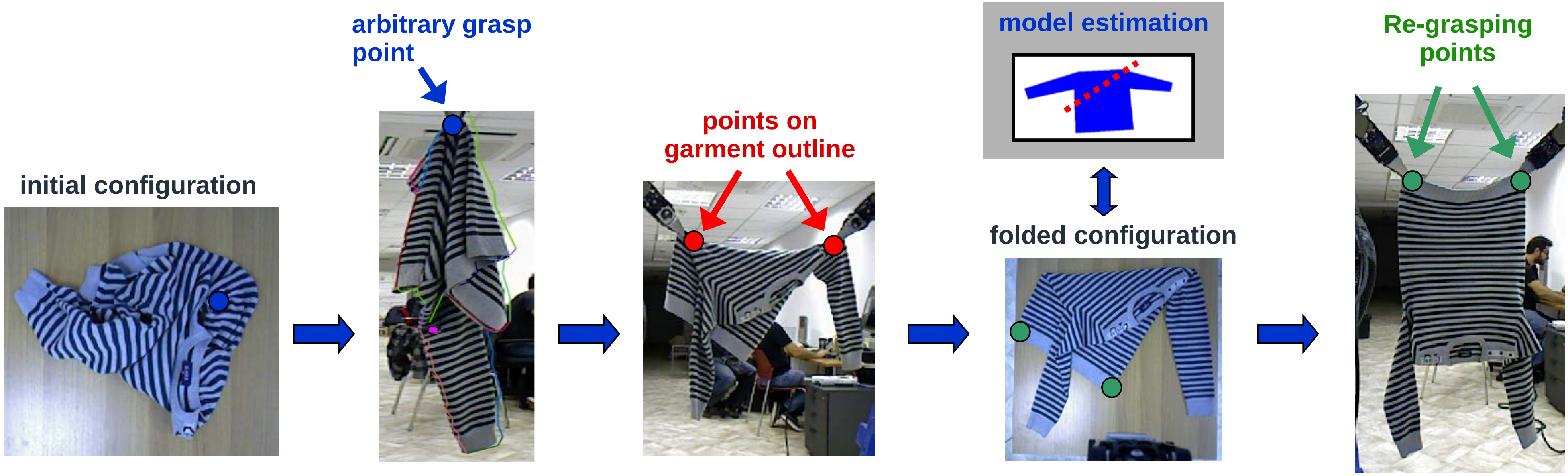
Block Diagram of unfolding Process



A Geometric Approach to Unfolding

- Grasp two points on the outline of the garment
- Analyze the 2D flat folded polygon to recognize garment type and key-points
- Re-grasp from key-points
- Novelty:
  - Robust outline point detection
  - Generic polygon unfolding.

Proposed Unfolding Strategy



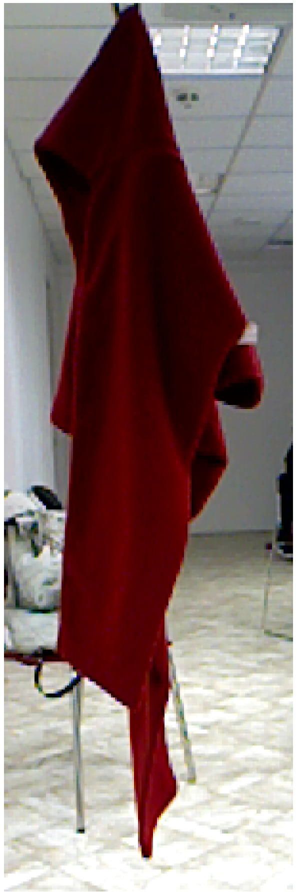
- ❑ Hang garment by an arbitrary grasp point
- ❑ Grasp two points on the **garment outline**
  - ❑ garment is brought to folded but planar configuration
- ❑ **Model** folded configuration by matching to unfolded templates
- ❑ Select two grasp points on the folded contour using the extracted model
- ❑ **Re-grasp** to an unfolded configuration

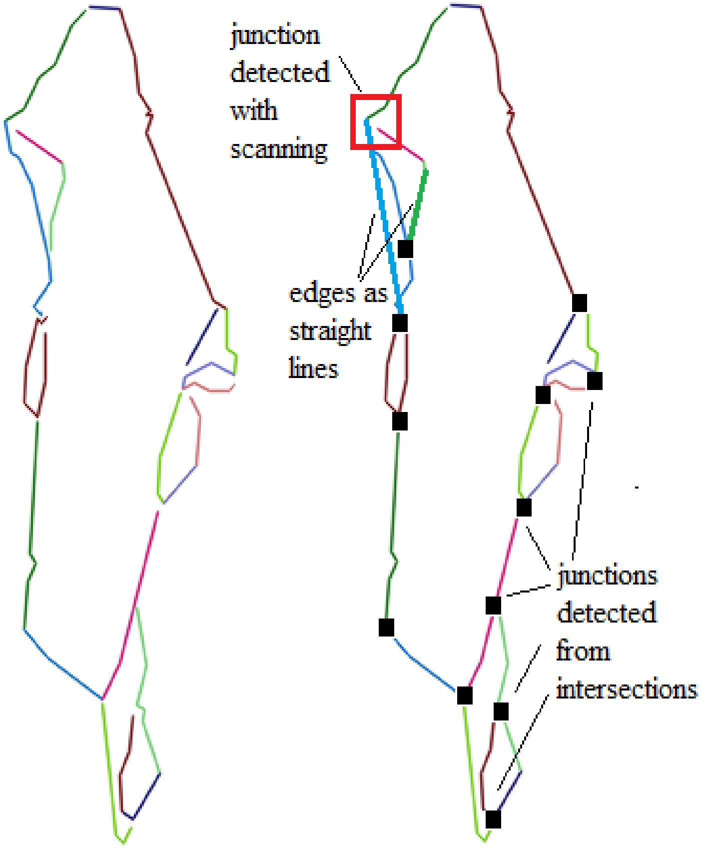
Finding grasping candidates

- Junctions formed at the bottom of folds
- Edges with orientation close to the horizontal surface

Extraction of edges and junctions

- ❑ Edge detection based on depth discontinuities
- ❑ Segmentation into separate straight lines with different inclinations
- ❑ Separation of each edge into sub-edges to calculate the precise location of junctions
- ❑ Detection of junctions from the intersections of the edges
  - ❑ using detailed representation
  - ❑ or scanning at the ends of open edges

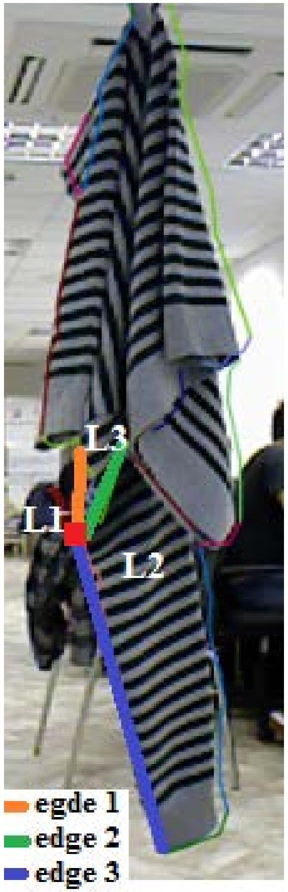


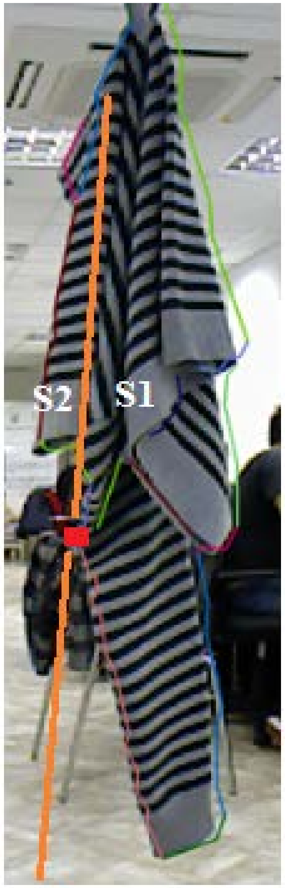


Detection of folds

A fold junction is characterized by the following features:

- It is a junction of 3 edges
  - at least 1 edge is heading upwards, towards the grasping point, and 1 downwards
- All edges belong to the same semi-plane defined by the edge heading to the grasping point
- Three layers with different depths are formed near the junction
  - in descending order from the deepest to the nearest:
    1. the layer that includes the semi-plane without the edges
    2. the lower layer of the semi-plane that includes the edges
    3. the upper layer of the semi-plane that includes the edges





Extraction of best grasping candidate

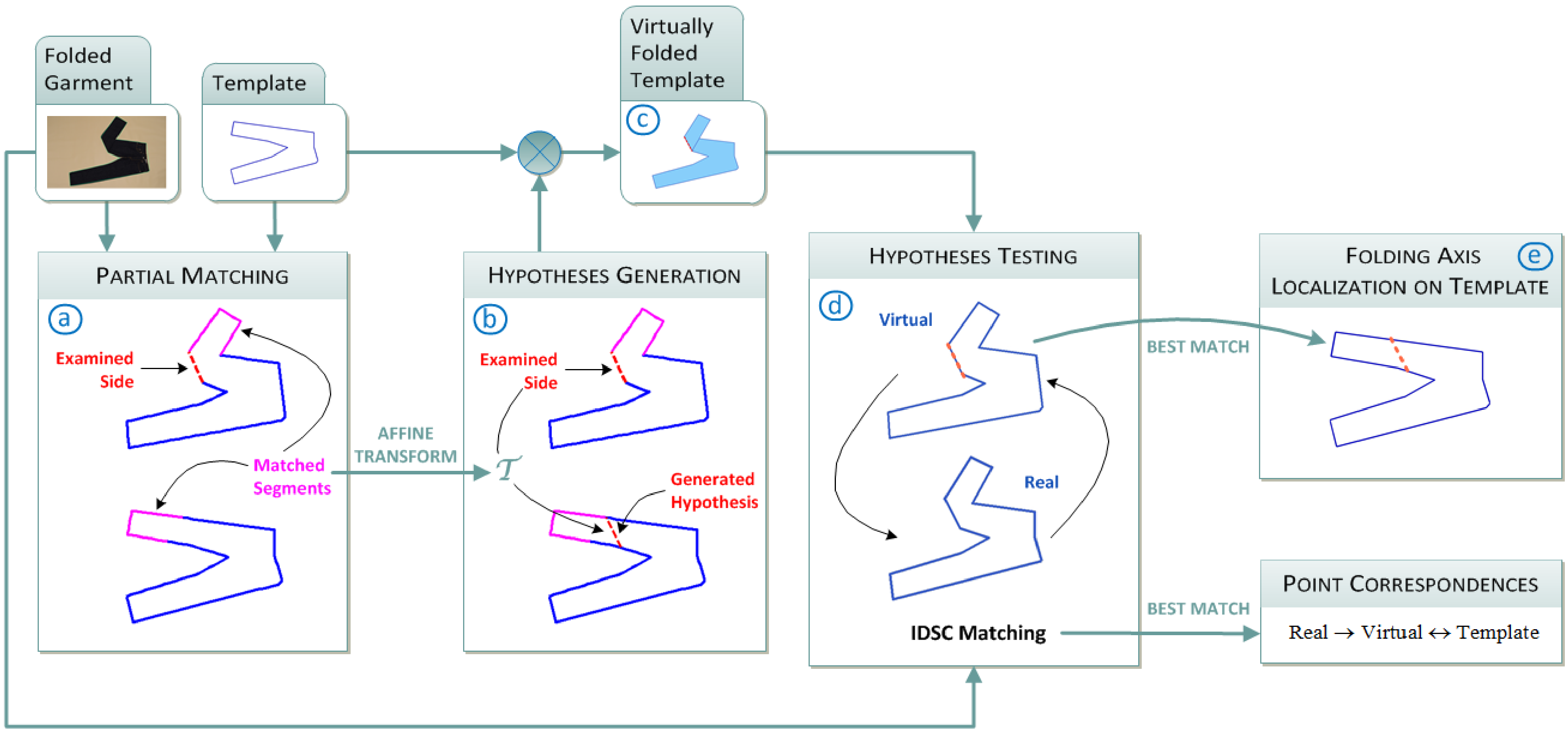
Procedure:

- The garment is rotated while depth images are taken from the Asus XtionPro range sensor
- The folds are detected for each image
- For each junction a score of the number of images where it is detected is calculated
- The junction with the highest score is chosen as a grasping point as long as
  - its score is higher than a threshold (3 images)
  - there is not another layer of the garment behind it for at least 3 cm (to allow grasping)
- If a good candidate is not found, the edge with the smallest inclination from the horizontal surface is chosen for grasping

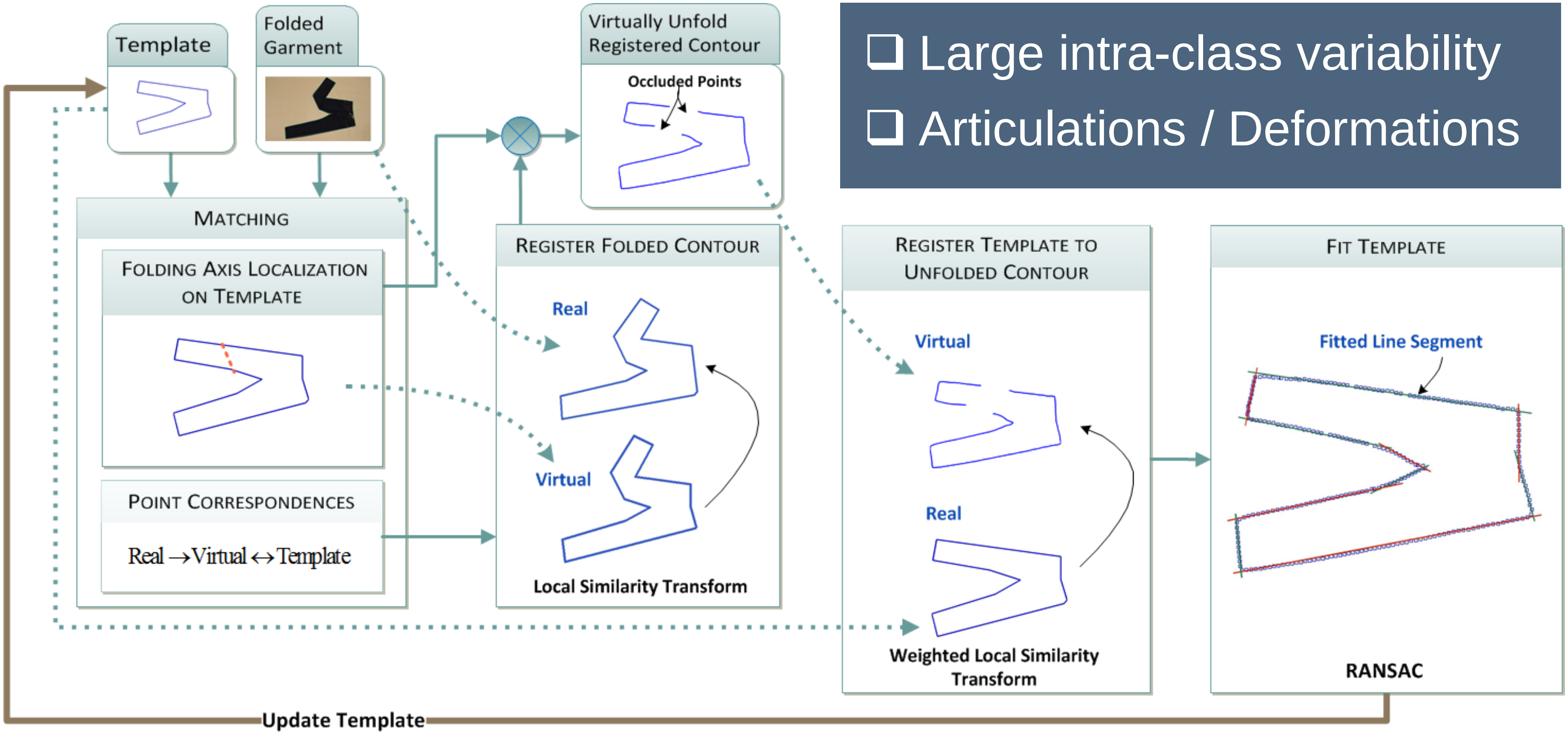
Experimental results

- 100 different configurations of various types of clothing were tested
  - the dataset included 5 long sleeved shirts, 5 T-shirts, 4 shorts, 4 trousers, 3 towels, 2 skirts
- In 95% of the cases, outline points were detected correctly
- In 2%, the folds were detected correctly but included an additional layer in their interior, preventing a correct grasp
- In 3%, the method failed to detect a correct outline point

Matching unfolded templates to folded garments*



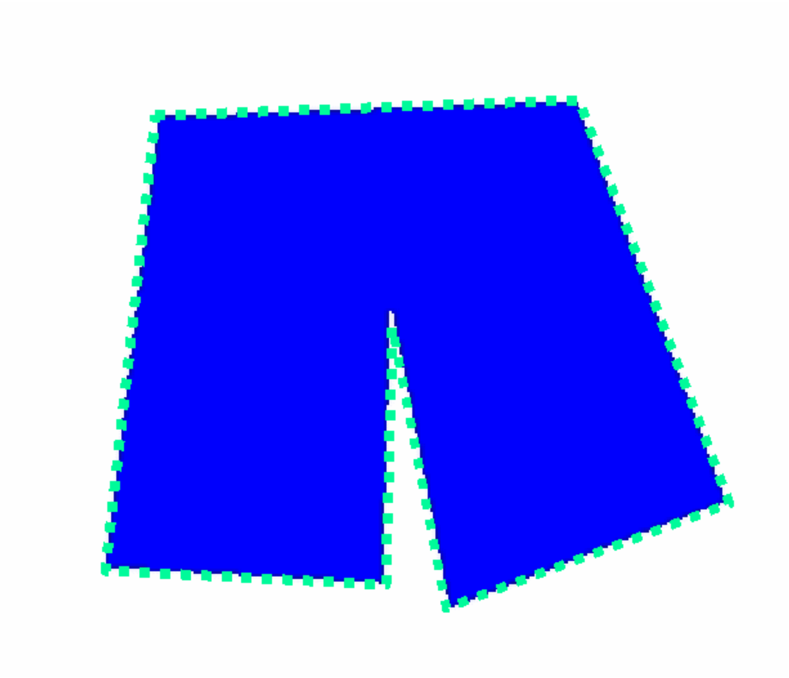
Fitting matched templates to garments



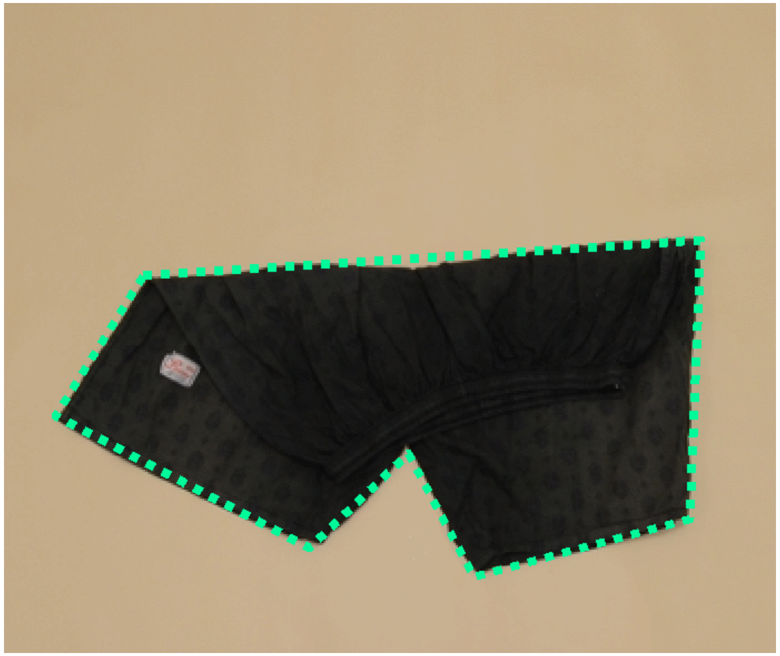
- ❑ Large intra-class variability
- ❑ Articulations / Deformations

Fitting example

Initial Template



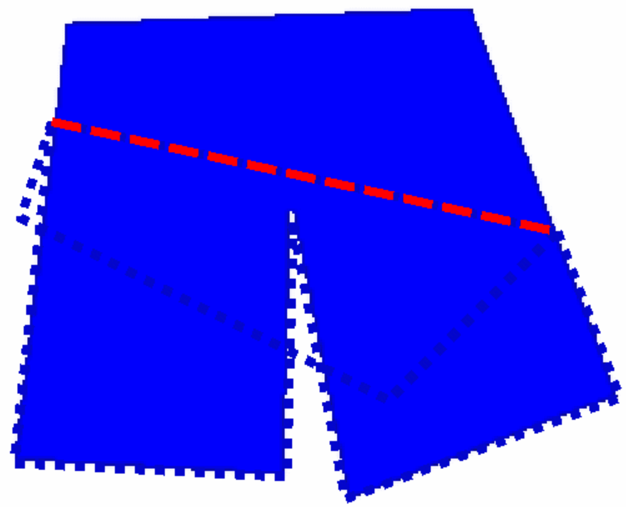
Folded Garment



Fitting example

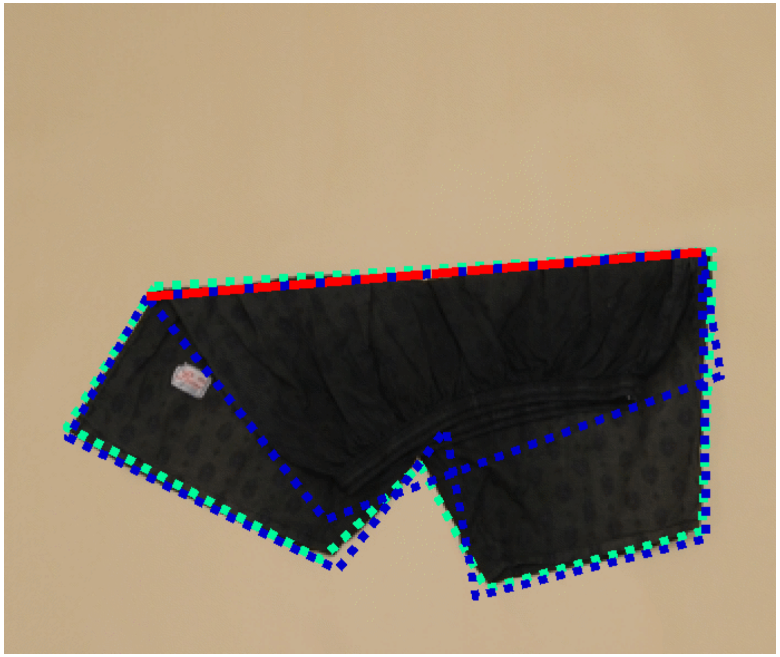
Initial Template

Repetition 0
Match cost : 34



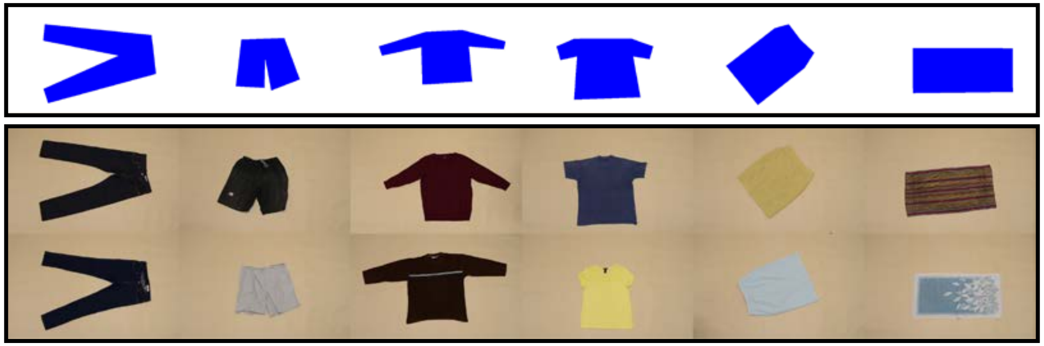
Folded Garment

Repetition 2, Match cost : 23



Experimental results

- 6 synthetic templates
- 12 articles of clothing
  - ❑ 4 or 5 manual folds for each
  - ❑ 54 total folds



Experimental Results

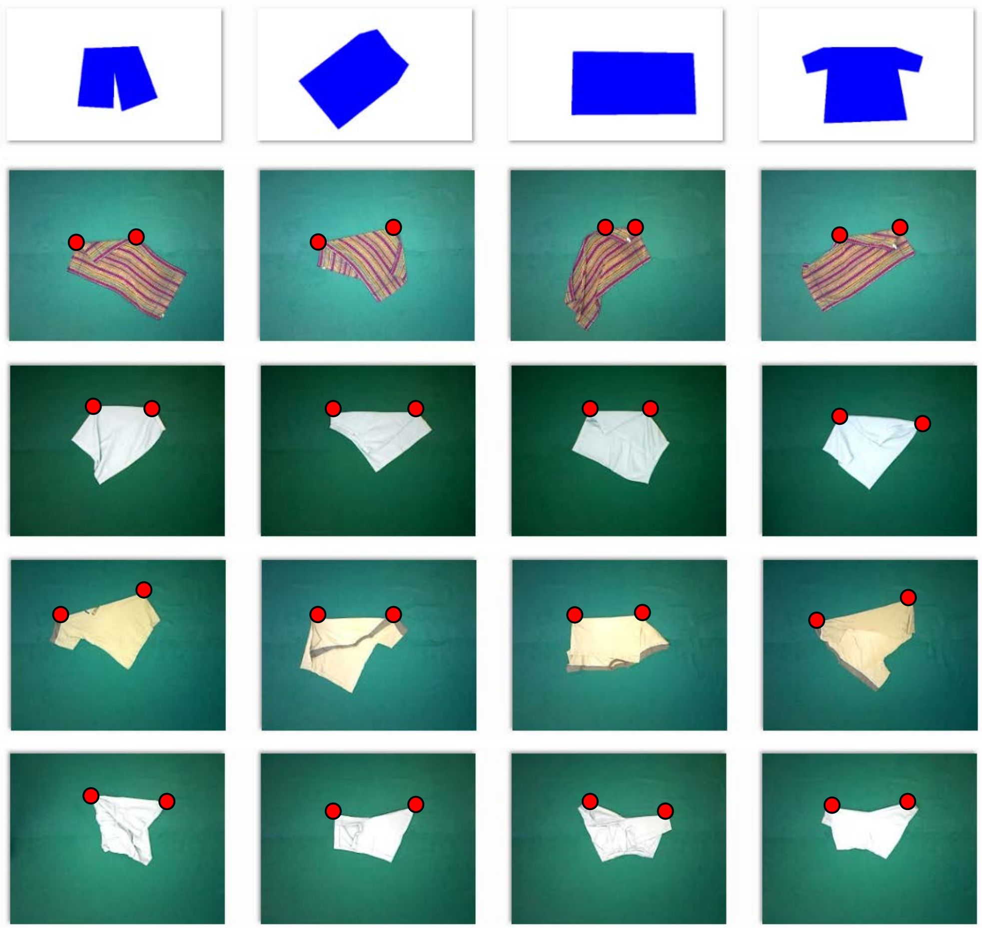
Type	CDR %		dA %	dθ°	MisMatch	MCD %
Trousers	100	(100)	1.5 ± 1.1	2.8 ± 2	0	11
Shorts	77.8	(77.8)	2.9 ± 2.3	1.6 ± 1.4	2	23.2
Shirt	90	(70)	3.9 ± 2.5	4.2 ± 3.8	0	20.9
T-shirt	77.8	(66.7)	4.8 ± 3.0	2.8 ± 3	2	29.3
Skirt	100	(88.9)	4.8 ± 3.2	3.6 ± 1.9	0	10.6
Towel	100	(42.9)	3.7 ± 3.7	3.1 ± 2.6	0	30.6
Overall	**90.7**	**(75.9)**	**3.6 ± 2.6**	**3 ± 2.5**	**4**	**20.4**

Discussion

- Fitting the templates improves matching performance
  - over 90% correct detection of folds
    - without fitting ~ 76% correct detection of folds
  - over 20% decrease in the match cost
    - between actually and virtually folded garments
- Detection accuracy seems sufficient for unfolding
  - dA results imply ~ 3.6 cm mean deviation between actual and estimated axes assuming
    - rectangular garments 1m in length
    - zero angle difference between actual and estimated axes
  - ~ 3^{o} mean deviation between actual and estimated axes
- Correct detection always resulted to correct model fitting

Experimental results: realistic dataset

- 4 synthetic templates
- 7 articles of clothing
  - ❑ grasped by two outline points (•)
  - ❑ laid on a table
  - ❑ 4 or 5 folds for each
  - ❑ 33 total folds
- Deformation due to hanging stage
- Trousers and shirts not considered
  - ❑ presented multiple folds
  - ❑ compensative actions needed



Experimental results: realistic dataset

Type	CC %	CRPD %	MisMatch
Shorts	90	75	1
T-shirt	100	80	2
Skirt	80	80	0
Towel	100	90	0
Overall	**93.9**	**81.8**	**3**

Conclusions

- Outline detection method brings garments to planar configurations without using lowest hanging point heuristic
  - workspace size is reduced
  - large garments are more easily handled
- Proposed template matching approach avoids
  - ad hoc rules
  - computationally costly simulations
  - training using machine learning
- 82 % success rate despite severe deformations introduced by hanging
- Future work
  - compensative actions to flatten the garment after placing it on the table
  - evaluation of unfolding strategy's overall performance
    - using the entire pipeline
    - considering trousers and shirts

Publications

1. Andreas Doumanoglou, Andreas Kargakos, Tae-Kyun Kim, Sotiris Malassiotis, "Autonomous Interactive Recognition and Unfolding of Clothes using Random Forests and Probabilistic Planning", ICRA 2014, Hong Kong, 31 May - 5 Jun, 2014 (to appear).
2. Andreas Doumanoglou, Andreas Kargakos, Tae-Kyun Kim, Sotiris Malassiotis, "Active Random Forests for Active Robot Vision: Unfolding Clothes Autonomously, ECCV 2014 (submitted)
3. Mariolis, I., Malassiotis, S.: Matching folded garments to unfolded templates using robust shape analysis techniques, in Computer Analysis of Images and Patterns, volume 8048 of Lecture Notes in Computer Science, pp 193–200. Springer Berlin Heidelberg, 2013
4. Mariolis, I., Malassiotis, S.: Modelling Folded Garments by Foldable Template Fitting. *Pattern Recognition* (submitted)
5. Triantafyllou, D., Mariolis, I., Malassiotis, S.: A Geometric Approach to Robotic Unfolding of Real Garments, in ICRA 2014 workshop on Advances in Robot Manipulation of Clothes and Flexible Objects (submitted)