Definition and Classification of Primitives for the Robotic Unfolding of a Piece of Clothing

Dimitra Triantafyllou and Nikos A. Aspragathos
Department of Mechanical Engineering and Aeronautics, University of Patras, Rio, Greece

Keywords: Clothes, Unfolding, Primitives.

Abstract: In this paper a dictionary of primitives is proposed that define critical features for the representation of a cloth's configuration so as to unfold it using a general manipulator. The primitives are defined, detected and classified according to geometrical criteria. Experimental results demonstrate the effectiveness of the detection and classification approach. Finally, applications are presented where the dictionary of the proposed primitives can be used, such as the definition of different types of folds of an unfolded fabric that can facilitate the unfolding task. Conclusion and suggestions for future work completes this paper.

1 INTRODUCTION

Recent years robotic scientists tend to give augmenting attention to the field of service robots. Robots that engage house works could relief people from a burden in their everyday life. A challenging area of house works for robotic scientists is the manipulation of non-rigid objects, such as clothes. Modelling and predicting the behaviour of fabrics presents huge difficulties due to the large deformations and the very low bending resistance of the fabrics.

A challenging task for the robotic handling of garments is their unfolding from a random configuration to a fully unfolded flat state. Since there are infinite possible configurations in which a garment can be found and there is no stable posture for grasping, as in rigid objects, researchers propose ways to diminish the garments' possible configurations. The transition of the garments into a group of known configurations facilitates the recognition of their state, hence their manipulation.

In order to achieve the reduction of the configurations, Osawa et al. (Osawa et al., 2007) proposed a technique, where the robot grasps a piece of clothing from a random point, picks it up, detects its lowest hanging corner, grasps it and then detects and grasps its new lowest hanging corner. In this way, garments result half folded in known configurations, facilitating their classification to a type of clothing and their unfolding. Cusumano-Towner et al. (Cusumano-Towner et al., 2011) suggested re-grasping the cloth's lowest hanging point to reduce the possible configurations. The goal was to recognize the specific article, by matching its outline with existing templates, and plan the sequence of manipulations, which bring the article to the desired unfolded state.

On the other hand, Kaneko et al. (Kaneko and Kakikura, 2001) used the relationships between the shadows that appear on clothes and the convex shape at the outline of clothing to detect points of the hemlines. Furthermore, they proposed a classification process, which matches the half folded clothes that occur after grasping the garment from two hemline points to predefined templates that suggest the type of clothing and its configuration. Maintin-Shepard et al. (Maitin-Shepard et al., 2010) implemented a vision algorithm that takes into account the sharpness of curvature of the cloth in order to find two neighbour corners and manage the unfolding of towels.

Besides the unfolding task, some researchers detect characteristic features met on clothes, such as wrinkles or loose folds (Han and Zhu, 2005),(Yamazaki and Inaba, 2009), (Yamazaki et al., 2011) . Han et al (Han and Zhu, 2005) suggested a two level generative model for cloth representation using shape from shading technique. An interesting aspect in their work is that they propose a dictionary of shading and fold primitives in order to detect loose folds on drapery and clothes. In previous work (Triantafyllou and Aspragathos, 2011) we tried to define and classify critical features on a piece of fabric. In this paper, a better classification with fewer categories is introduced, simplifying the problem, and an efficient implementation methodology is presented. Ad-

Triantafyllou D. and A. Aspragathos N..
Definition and Classification of Primitives for the Robotic Unfolding of a Piece of Clothing.
DOI: 10.5220/0005155704170422
In *Proceedings of the International Conference on Knowledge Engineering and Ontology Development* (KEOD-2014), pages 417-422
ISBN: 978-989-758-049-9

ditionally, possible applications of the methodology are proposed.

Particularly, in this paper, a dictionary of primitives for critical features that define the configuration of a piece of clothing is introduced. The ”words” of the dictionary include types of junctions, such as ”L” and ”arrow” junctions, which constitute components that are used in bibliography (Shapiro and Stockman, 2001) for perceiving 3D objects in 2D images. Inspired by this approach, we use the same primitives to define the configuration of a piece of clothing. Nevertheless, in the presented case the primitives do not represent the joins of the facets of a 3D object but indicate the existence of folds, overlappings, edges and corners on a garment. Furthermore, machine vision techniques are used to detect and classify these critical features into categories. The dictionary can be used for any configuration under the restriction that it occurs from holding the garment in the air from its outline and then laying it onto a table. The main difference from previous works that aimed at unfolding clothes is that we try to analyse and comprehend the configuration of the garment no matter its shape. We do not use predefined templates, so even pieces of fabric with unusual shapes can be handled.

The outline of this paper is as follows. Section 2 presents the dictionary of primitives in detail, while in section 3 possible applications are described. In section 4, the detection and classification of the primitives is implemented. Finally, section 5 includes experimental results and section 6 some conclusions and ideas for future work.

2 INTRODUCTION OF PRIMITIVES FOR THE CLOTH UNFOLDING

The infinite degrees of freedom of clothes result in infinite possible configurations. The introduced primitives concern only configurations, where gravity is used to convert crumbled clothes (Fig 1.b) into a more straightened, crisp state. In particular, the accepted configurations can occur after lifting the garment in the air from a point at its outline when it is fully unfolded (Fig 1.a), so that all major wrinkles are removed, and then lay it on a working table, as in Fig 1.c. In this paper, configurations on a table are considered, although the differences when holding the garment in the air are small. An easy way to detect an outline point is to apply the lowest hanging point technique as suggested in (Osawa et al., 2007), (Cusumano-Towner et al., 2011). So, when a garment grasped from a random point is hanging, its lowest point is an outline point.

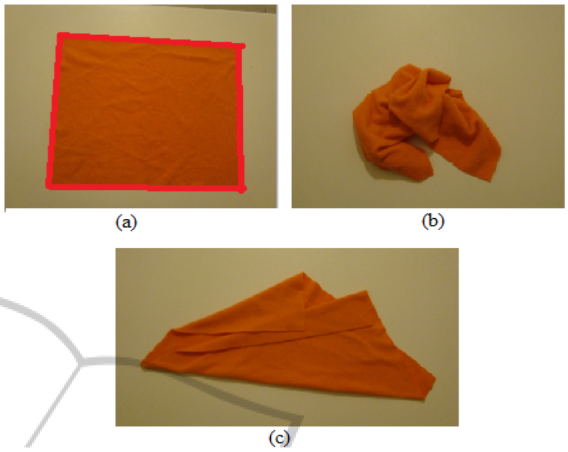


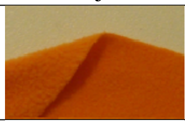
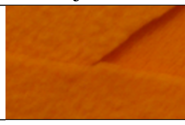
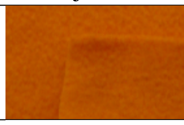
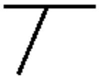
Figure 1: Configurations of the cloth: (a) the outline of the cloth when it is fully unfolded, (b) a piece of clothing in a crumbled configuration, (c) the piece of clothing after it is held in the air from its outline and laid on a working table.

Figure 2: Critical features for the unfolding task and their characteristic points of intersection: (a) a fold, (b) an overlapping.

The primitives of the proposed dictionary are geometric features that describe folds, overlappings, parts of edges and corners on the surface of the lying piece of clothing. We define as a fold the result of bending a cloth over upon itself (Fig 2.a). On the other hand, an overlapping occurs when a part of a cloth covers partly another one, if the two participating parts are not located next to each other in the garment’s unfolded configuration (Fig 2.b). To indicate the existence of a fold or overlapping, the detection of the junction, where the participating layers intersect is sufficient (Fig 2). Furthermore, the term ”corners” refers only to the corners that are located at the outline (Fig 1.a)of the unfolded cloth.

The geometrical features, that constitute the introduced primitives, are types of junctions which are classified according to the number of edges and the size of the angles they form into ”I”, ”L”, ”T” and ”arrow” junctions (Table 1). So, a fold is detected by an ”arrow junction”, an overlapping is met when a ”T” junction occurs, a part of an edge is an ”I” junc-

Table 1: The primitive features for the unfolding task.

Features	fold	overlapping	corner	edge
Junction's type	"arrow" junction	"T" junction	"L" junction	"I" junction
Junction's type				
Junction's schema				

tion, while the corners of the garment are indicated by "L" junctions. Furthermore, an "L" junction could also indicate a "hidden fold", which is actually a fold whose folded part is hidden behind the visible part of the garment. One way to distinguish a hidden fold from a cloth's corner is to lift the "L" junction with the robot and check if an "arrow" junction was hidden at the side of the cloth that was not visible. In addition, the edges of a "T" junction dictate which part of the cloth is overlapped and which one overlaps the other part. So, if we consider the "T" junction as an intersection of one edge to the middle of another edge, then the part of the cloth that includes the first edge is overlapped by the part of the cloth with the second edge.

The relationships described in the previous paragraph cover a big part of the junctions that can be found on a lying piece of clothing. Other types of junctions could rarely occur in the configurations under consideration thanks to gravity and for now are not taken into account. In addition, we cannot exclude the possibility that the types of junctions used as primitives could occur from other circumstances than the mentioned ones. Nonetheless, the reasonable location on the cloth and the appropriate combination of primitives can largely diminish false correspondences between the primitives and their meaning. In section 3, apart from examples that prove that these mistakes can be avoided, different ways that the primitives can be appropriately connected and form layers are described.

3 USES OF THE PRIMITIVES' DICTIONARY

The introduced features can provide information for the extraction of the garment's layers in order to facilitate the unfolding task. The goal of this paragraph is not to classify the layers based on the proposed primitives, although it will be presented in future work. The aim is to demonstrate the utility of the proposed dictionary by showing how its primitives, detected in appropriate combinations, can describe different types of layers. So, in the same way that words put in an appropriate order form sentences with different meanings, the primitives of the proposed dictionary, detected in an appropriate order, define layers that occur from different configurations.

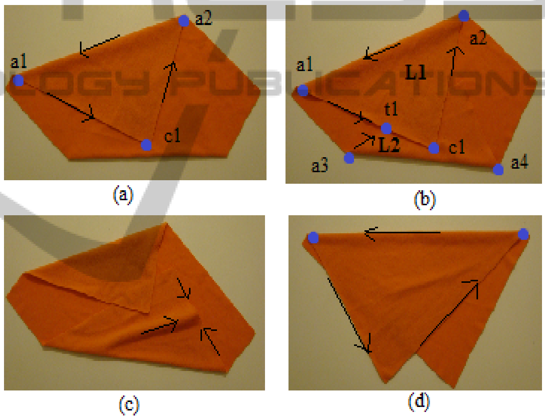


Figure 3: Primitives and their role to extracting edges for the unfolding task: (a) extraction of a layer that can be unfolded, (b) detection of an overlapped layer and a layer that can be unfolded, (c) the effect of a "loose fold", (d) extraction of a layer when the cloth is in a half folded configuration.

In Fig 3.a layer L can be defined by a sequence of the proposed primitives. Starting from one of the arrow junctions (e.g. a1), which implies the existence of a fold, and following its internal edge by detecting "I" junction primitives, we result in the "L" junction c1, meaning a corner. Continuing in the same way, arrow junction a2 is met and finally we result again to arrow junction a1. This sequence of primitives suggests the existence of a layer that can be unfolded, since it does not include any "T" junction that implies overlapping. Similarly, in Fig 3.b, starting from arrow junction a3 and following its internal edge we reach a "T" junction. The edge that led to the "T" junction implies that the layer that we started detecting (L2) is overlapped by another layer (L1), as a result it cannot be unfolded. On the other hand, the extraction of the layer L1 can be conducted in a similar way as in Fig 3.a, since, in this case, the ”T” junction suggests that layer L1 overlaps another layer. So, depending on the orientation of a ”T” junction different conclusions about the unfoldability of a layer can occur. In addition, in Fig3.c, the ”T” junction created by the ”loose fold” cannot affect the correct extraction of an unfoldable layer since its position does not suggest that is overlapped.

In addition, the primitives’ dictionary could also be used for unfolding in situations that the garment is brought in a half folded configuration by using the ”lowest hanging point” technique, as suggested in (Osawa et al., 2007), (Cusumano-Towner et al., 2011). The detection of the layer to unfold in addition to the detection of possible overlaps can be conducted in a similar way as described in the previous paragraph (Fig 3.d).

Finally, a scenario that could be investigated is the detection of folds indicated by ”arrow” junctions, in order to find points at the outline of the garment under unfolding so as to recognize the type of clothing and unfold it as in (Kaneko and Kakikura, 2001). In (Kaneko and Kakikura, 2001) the detection of such points is made using the shadows created on the garment in combination with the convex shape created at the outline of the hanging cloth near the fold. Since folds do not always create sufficient shadow for detection we believe that the detection of ”arrow” junctions can provide more candidates for outline points, but this is left as future work.

4 THE DETECTION AND CLASSIFICATION OF THE PRIMITIVES

In this section a method for the implementation of the primitives’ detection and classification is presented. The experiments are made on monochromatic clothes using RGB images; nevertheless we have experimental evidence that the same procedure could be successful on multicolour garments with a stereo camera. The pictures are taken from a 20 cm distance from the working table where the clothes are lying and no specific lighting conditions are used.

The first step is to extract edges from the grayscale picture depicting the primitive under detection. Bilateral filtering (Tomasi and Manduchi, 1998) , which enhances the edges, is applied (the Gaussian window is 20 pixels, the spatial domain standard deviation is 2, while intensity domain standard deviation is 0.6).

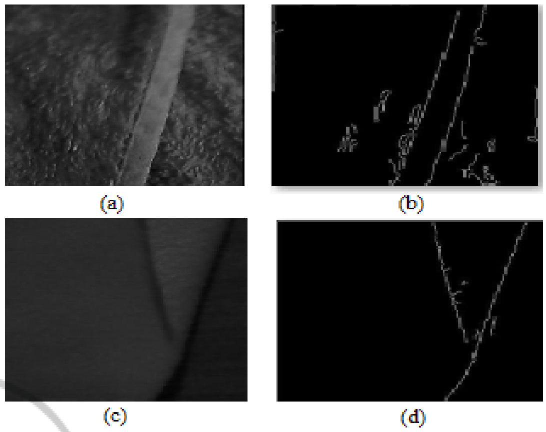


Figure 4: Examples of primitive features and their edge detection: (a) a part of a towel’s edge, (b) the edge detection of the towel’s edge, (c) a fold on a fleece piece of clothing, (d) the edge detection of the fleece’s fold.

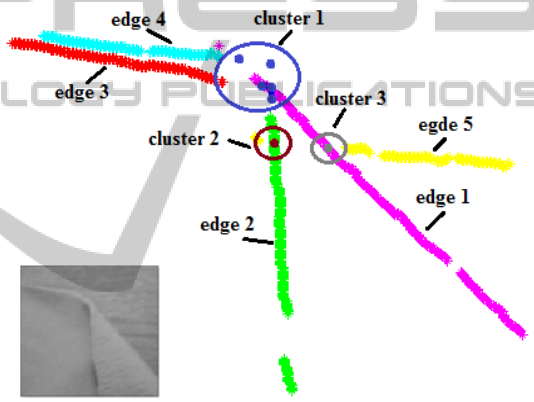


Figure 5: The detected edges from Ransac algorithm and the clusters of their intersection points.

Then an automated procedure is used for a Canny detector threshold that diminishes the noise, while extracting the edges. Particularly, the threshold is reduced until the ratio of the pixels that belong to the edges and the noise to the rest pixels of the image becomes smaller than 0.025. In this way, while the ratio is reduced, the noise pixels that are decreased are more than the decreased edge pixels, since they are enhanced by the bilateral filter. This procedure provides satisfactory edge detection for different kinds of clothes regardless if their surface is smooth or rough (e.g. towel). For example in Fig 4 primitives from a towel and a fleece piece of clothing are extracted without particular noise.

To proceed, different edges are detected using Ransac algorithm (Fig 5). Up to five edges are detected in order to reduce computational cost and avoid the detection of small edges created from noise. Several of the detected edges might be double, meaning

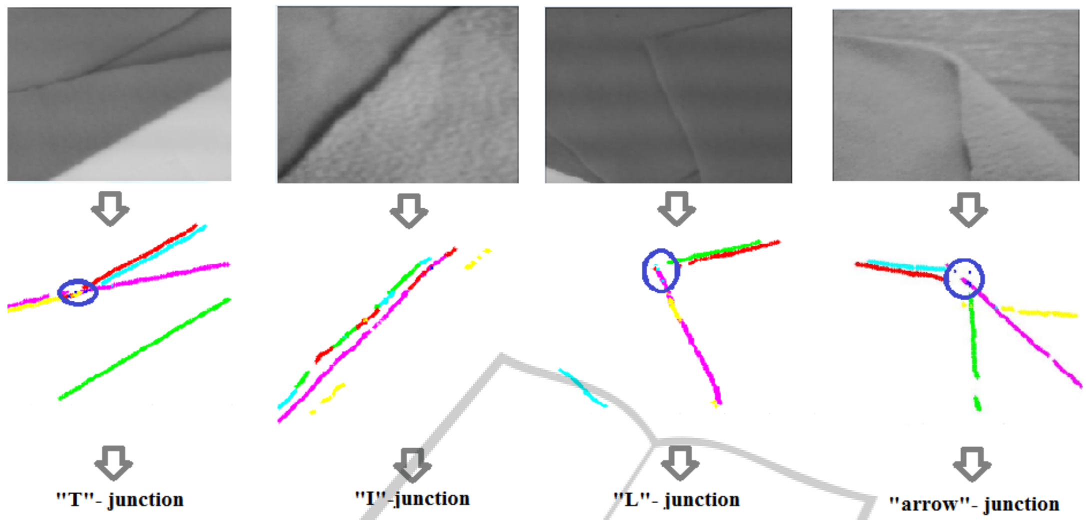


Figure 6: Examples of the detection and classification of primitives. In the first row the grayscale images of the primitives are presented while in the second row the corresponding detected features are depicted. For each image different edges are depicted with different colors while the cluster that represents the final point of intersection is marked with a blue circle. The third row contains the results of the classification.

that an edge and its shadow can be detected as two different edges, that Ransac split an edge in two parts, that the cloth has a thick hemline creating two edges etc. Such examples can be seen in Fig 6. Furthermore, the detected edges that participate in a junction usually do not intersect to only one point but within a small area (cluster 1 in Fig 5). To detect this area the points of the edges' intersections are calculated and clustered according to their distance from each other using the single-link hierarchical clustering method (the maximum relative distance of the cluster's elements is 25 pixels). The cluster including the highest number of elements is chosen as the junction of interest (Fig 5).

Then, the number of the edges participating to the junction is calculated. Double edges are unified, based on their location and inclination, since they are almost parallel and close to each other (eg in Fig 5 edge 3 and 4). Once the junction of interest and the number of intersecting edges is found, the angles created by the edges of the junction are measured to determine the type of junction. So, according to its geometry, the junction is classified to one of the primitives defined in section 2.

5 EXPERIMENTAL RESULTS

The detection and classification algorithm was tested in 40 different samples using 4 different monochromatic fabrics. In 80% of the cases, the junctions were detected and classified into the correct category of primitives. Examples depicting the correct detection and the classification of the primitives can be seen in Fig 6. On the other hand, in 7,5% the arrow junctions were mistaken as other type of junction because of the big curvature of the bended layer of fabric near the junction and the shadow created (Fig. 7.a). With straightening movements made by the robot, this curvature could be diminished and better results would be obtained. Furthermore, in 7.5% the noise created problems extracting wrong edges and in 5% the junction was near the frame of the picture, so one of the participating edges was not big enough to be detected (Fig. 7.b). The additional evaluation of a second picture, slightly dislocated from the first one, is considered as a measure that could enhance the results and will be investigated in the future.

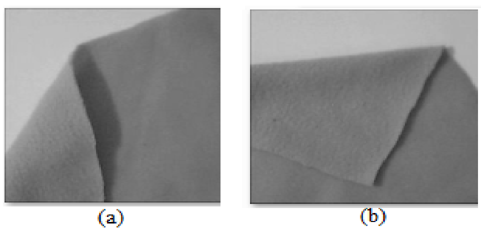


Figure 7: Examples where the method failed to categorize correctly the primitives: (a) the folded part creates shade because of the big curvature near the point the fold is formed, (b) one of the edges participating to the arrow junction is not big enough to be detected.

6 CONCLUSION

In this paper, a dictionary of primitives, that define critical features on a piece of clothing for its unfolding, is proposed. The dictionary can be used for pieces of clothing and fabrics of various shapes, since we do not use restricting predefined templates. The primitives are detected and classified based on geometrical criteria.

The combination of primitives can represent different configurations of a garment laid properly on a table. Layers that can be unfolded, folds, overlappings and corners of the garment can be detected and used for planning manipulations for the unfolding task. The detection and classification of the primitives is implemented using machine vision techniques. Results show the effectiveness of the proposed approach.

As future work, the implementation of layers' extraction and manipulation in order to unfold a piece of clothing is planned. Additionally, a scenario to be investigated is the detection of folds, in order to find points at the outline of the garment under unfolding so as to recognize the type of clothing and unfold it.

REFERENCES

Cusumano-Towner, M., Singh, A., Miller, S., Brien, J. O., and Abbeel, P. (2011). Bringing clothing into desired configurations with limited perception. In *IEEE International Conference on Robotics and Automation*.

Han, F. and Zhu, S. (2005). Cloth representation by shape from shading with shading primitives. In *Conference in Computer Vision and Pattern Recognition*.

Kaneko, M. and Kakikura, M. (2001). Planning strategy for putting away laundry - isolating and unfolding task. In *IEEE International Symposium on Assembly and Task Planning*.

Maitin-Shepard, J., Cusumano-Tower, M., Lei, J., and Abbeel, P. (2010). Cloth grasp point detection based on multiple-view geometric cues with application to robotic towel folding. In *IEEE International Conference on Robotics and Automation*.

Osawa, F., Seki, H., and Kamiya, Y. (2007). Unfolding of massive laundry and classification types by dual manipulator. In *Journal of Advanced Computational Intelligence and Intelligent Informatics*.

Shapiro, L. and Stockman, G. (2001). *Computer Vision*. Prentice Hall, 1st edition.

Tomasi, C. and Manduchi, R. (1998). Bilateral filtering for gray and colour images. In *IEEE International Conference on Computer Vision*.

Triantafyllou, D. and Aspragathos, N. A. (2011). A vision system for the unfolding of highly non-rigid objects on a table by a manipulator. In *International Conference on Intelligent Robotics and Applications*.

Yamazaki, K. and Inaba, M. (2009). A cloth detection method on image wrinkle feature for daily assistive robots. In *Conference on Machine Vision Applications*.

Yamazaki, K., Nagahama, K., and Inaba, M. (2011). Daily clothes observation from visible surfaces based on wrinkle and cloth-overlap detection. In *Conference on Machine Vision Applications*.