Visual Feature Extraction and Topological Analysis for Inferring the Configuration of Hanging Cloth

Dimitra Triantafyllou
Information Technologies Institute
CERTH
Thessaloniki, Greece
Email: dtriant@iti.gr

Sotiris Malassiotis
Information Technologies Institute
CERTH
Thessaloniki, Greece
Email: malasiot@iti.gr

***Abstract*—This paper presents algorithms for inferring the configuration of a hanging rectangular piece of clothing from a single range image. This is the first step towards unfolding a towel using a dual arm robot. The algorithm employs feature detection followed by a representation of the surface by means of several layers of overlapping 3D polygons. By analysing the topology of these layers, their mapping to the original (unfolded) rectangle is achieved. The final mapping allows reconfiguration on the garment or grasp planning to achieve unfolding.**

I. INTRODUCTION

Last decades, there is a tendency to develop home service robots that will exempt people from tedious, household chores. Tasks, such as laundry manipulation and folding constitute challenging research areas because of the highly non-rigid nature of clothes. The infinite configurations of a garment create difficulties to the recognition of the state it is into and to the detection of the desirable grasping points for its manipulation.

In the robotic literature, three approaches for the detection of grasping points for the unfolding task of clothes can be distinguished. The first category detects characteristic features of the clothing article and uses them as grasping points. For example, in the case of a towel, its corners are considered good grasping candidates [2], [3], whereas for a polo-shirt its collar [4].

In the second approach, initial grasping manipulations bring the garment in a more or less known configuration, held by two robotic manipulators, so as to facilitate the further selection of grasping points. Osawa [5] and Cosumano-Towner [1] used a heuristic technique to achieve it. By iteratively grasping the lowest hanging points of the article, each kind of garment is led into a limited number of configurations (e.g. a towel would be grasped only by two non adjacent corners). Similarly, Kaneko [6] detected parts of the hemline and re-grasped them so as the robot to hold the garment from two different edges of the hemline. In both cases, in the end, the garment is either unfolded or folded in half. The knowledge of the configuration, facilitates the detection of the necessary grasping points for further unfolding manipulations, when needed.

In the third approach,the researchers estimate the garment's configuration when it is hanging from one point. The approach adopted by Kita et al. [7] is to use a simplified mass-spring model of the hanging garment and fit this model to point cloud data thus directly inferring its configuration. On the other hand, Bersch [8] used cloud representation and various fiducial markers located on a T-shirt for the estimation of its configuration. Each of the markers corresponded to a specific point on the T-shirt in a flat, unfolded configuration. The selection of the next grasping point, in order to unfolded it, was based on a greedy policy that chooses the point with the smallest geodesic distance to the target grasping points (in the particular case, the shoulders of the T-shirt).

There are several limitations at the techniques mentioned above. The detection of characteristic features such as corners [2], [3] or collars of polo-shirt [4] can be problematic due to noise and occlusions. In addition, the rotational movement of the towel in front of a camera for better recognition of its configuration [8] and detection of features [2] and the algorithms for the cloud representation of the garment are very time consuming. Furthermore, the lowest point manipulation [5], [1] has the limitation that, apart from being blind of true garment structure, becomes problematic with long items. Finally, understanding the configurations by model fitting [7] requires that the dimensions of the clothing articles are already known.

In contrast to previous work, our goal is to infer the possible configurations of a towel of unknown dimensions given only its visible part. This approach reduces the number of manipulations required to bring the towel in a desired configuration or infer key-points. In particular, in the presented approach, the topology of the visible features of a hanging towel is analysed. Firstly, primitive features, such as edges and junctions of the towel, are extracted with the help of a range sensor. Then, the towel, which is hanging in the air from one of its corners, is decomposed into layers. For each layer, the corresponding position in an unfolded configuration of the towel is obtained. Based on the set of obtained configurations we may facilitate the task of selecting grasping points or proposing a re-grasping strategy so that the grasping points will become visible.

II. FEATURE EXTRACTION

The first step for the topological analysis of the towel is the extraction of critical features such as edges and junctions that will provide all the information for the decomposition of

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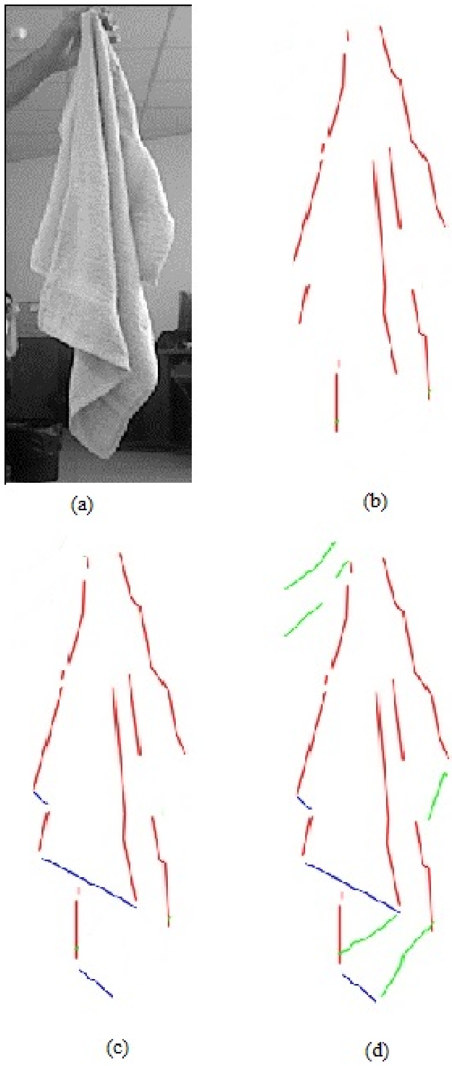

Fig. 1. Detected edges of all the categories

the towel into layers. The extraction of these features and the way the towel is decomposed into layers is described in the two following subsections.

A. Detection of the towel's edges and junctions

The detection of the towel's edges and junctions is made in two phases. Firstly, the edges or parts of them are detected while in the second phase these edges are connected to each other in order to form longer edges or junctions. These features are extracted from 3D information of the towel's visible side, which is acquired from a range sensor (Asus Xtion).

Edge detection is performed on the 3D image. We employ a Hough transform to classify the edges of similar orientation in: 1) vertical, 2) edges that incline leftwards, 3) edges that incline rightwards and 4) completely horizontal. Due to the noise of the data that are used and the curvature of the edges to be detected there is a tolerance on the inclination of the edges of each category. Next, all the pixels that are located close to each other and belong to edges that are classified into the same category are connected in order to form bigger edges (Douglas-Peucker is used in order to create polygonal

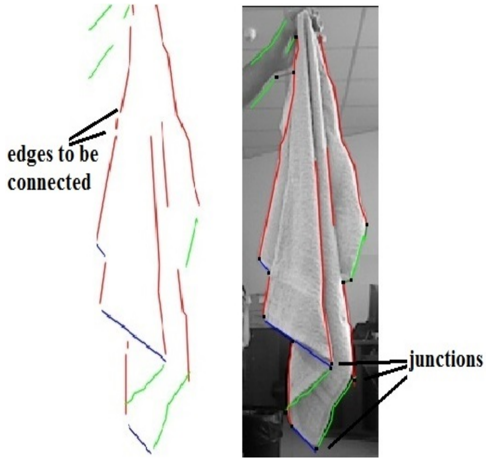

Fig. 2. Junctions and connected edges

lines from the pixels). In Fig. 1, the edges that are created after this procedure are depicted. Firstly, the vertical edges are detected (Fig. 1.b), then, the edges that incline leftwards (Fig. 1.c) and, finally, the edges that incline rightwards are added (Fig. 1.d).

At this phase, several edges of the towel are detected but it is not yet known how their are connected to each other. According to their classification, the edges might be connected to a bigger one or create a junction. In particular, two edges of the same category can be unified, when the higher end of the first one is close to the lower end of the second one, or they can create a junction, when both lower/higher ends are close to each other. In addition, when the end of an edge is close to another edge of different category, then a junction is created. In Fig. 2 the edges' connection and the detection of junctions is depicted.

B. Decomposition of the towel into layers

For the extraction of the towel's layers, the towel is held by one of its corners. Its edges and junctions of edges are considered known. These features are either formed by folds or belong to the outline of the towel when it is fully extended. Folds, which are responsible for the formation of more than one layer, usually start close to the grasping point. In our method, all the edges that begin from a fold close to the grasping point are considered to start from it for convenience, without lose of generality.

The edges can be divided in two categories: 1) the vertical edges and, 2) the horizontal edges, which actually correspond to the categories 2,3 and 4 mentioned in the previous subsection (Fig 3.a). The vertical edges usually end up to the grasping point. Sometimes, due to overlapping, there are vertical edges with the part close to the grasping point hidden from the camera. Nevertheless, for the formation of layers, the visible part, which is inclined towards the grasping point, is extended to it (Fig 3.b). In addition, there are vertical edges that might intersect far from the grasping point. These cases occur when a part of the towel is hidden behind the visible side (Fig. 4.d).

The junctions that are taken into account for the extraction of layers are points of intersection of two vertical or two

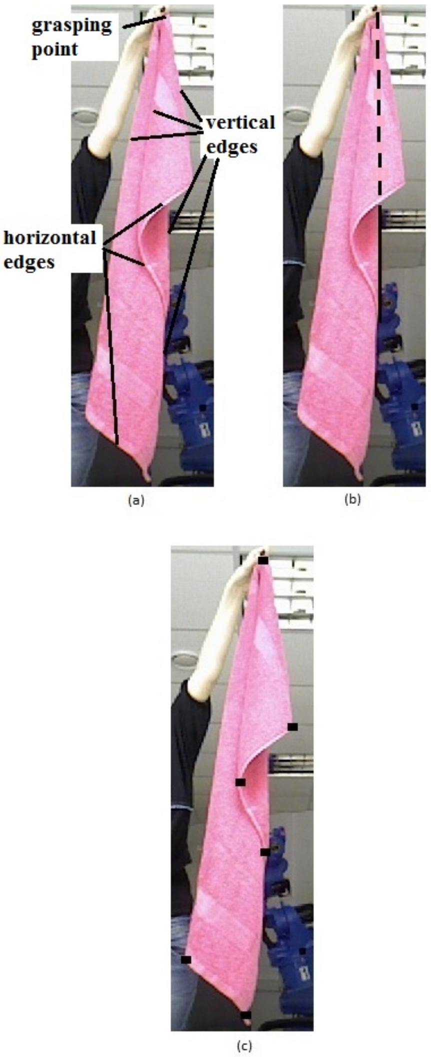

Fig. 3. Edges and junctions of a hanging towel

horizontal lines or points where the end of a horizontal edge intersects with a vertical edge. In Fig. 3.c the junctions that are taken into account for the extraction of the towel's layers are depicted with small black squares. For the extraction of the towel's layers, the following procedure is applied iteratively. The lowest corner, not been examined yet, is picked and the two junctions it is connected to, that lead to higher located junctions, are examined. These junctions are connected to each other (in cases where the layer is triangular) or are both connected to the same junction (the layer is quadrangle). For example in Fig. 4.b, junction j5 is connected, through edges e4 and e5, to junctions j4 and j6, which are connected to each other with edge e6. So, a triangular layer, formed by the edges e4, e5 and e6, is detected. Similarly, a rectangular layer, formed by the edges e1, e2, e3 and e4, is detected in Fig. 4.a. If a junction is used as the lower junction of a layer then it cannot be used again in another layer. Actually, every junction can participate in N-1 layers, where N is the number of edges intersecting at this junction. The layers are represented by triangles or rectangles for convenience and in order to reduce computational complexity. In Fig. 4, the detected layers of a random configuration of the towel are highlighted.

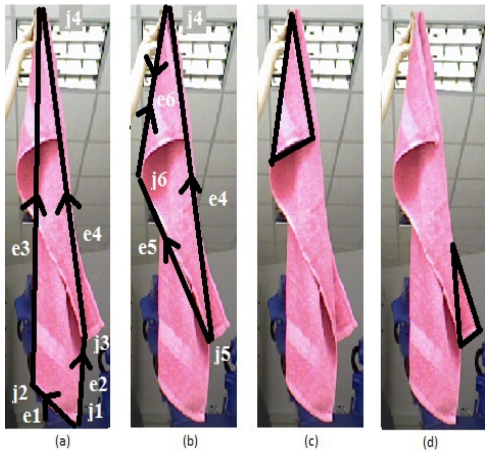

Fig. 4. Detection of layers

III. Topological analysis

When the decomposition of the towel into layers is completed, their topological analysis begins. For each layer, its relative position to the other layers in an unfolded configuration of the towel is found. In addition, the layers' edges are mapped to the towel's outline edges when it is unfolded.

A. Problem description

The difficulty of the problem is that a towel, like any piece of clothing, is a highly deformable object with infinite degrees of freedom. So, although holding the towel from one of its corners reduces the number of configurations, the state of the towel cannot be predicted. In addition, the presented method uses data detected from only one side of the hanging towel. This means that there are hidden parts of the towel, in other words, hidden information about its configuration. Finally, another difficulty is that the layers are not flat to the surface of the camera, as a result, they cannot be used as parts of a puzzle that fit perfectly with each other and form an unfolded flat towel (even if it is with missing parts, as mentioned before).

The topological analysis is based on restrictions that are dictated by the towel's rectangular shape and observations concerning the configurations of a towel hanging from one of its corners. These may be formulated as rules that determine the connection of the layers and indicators that suggest a preference to a candidate configuration. Firstly, the relative position of the layers with each other is defined and then their edges are mapped to the outline of an unfolded, straightened towel.

In the proposed method, the layer with the lowest hanging point is considered stable(as it is mentioned in the next paragraph, this layer includes one of the diagonals of the towel). Starting from the next layer with the lower corner, one by one, the rest of the layers, are placed in the right or the left side of the already located layers (this applies for the layers starting from the grasping point- layers that start from a lower point are examined in the end). Depending on the side it is placed, the layer is left as it is or its symmetric is used. If there is a rule that bans one of the two possible positions or that

Fig. 5. The towel in an unfolded and a hanging configuration

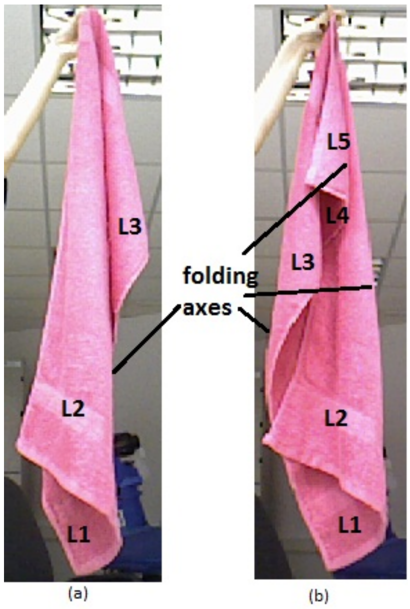

Fig. 6. Connection of layers

dictates a definite connection of one layer with another, then there is only one solution for their connection. In cases where both positions are possible, there are indicators that suggest one of them without excluding the other one. When all the layers are taken into account, all the possible configurations are evaluated and, according to the indicators, one of them is the one that corresponds to the real configuration. Since the winning configuration is found, the edges of the layers are mapped to the sides of an unfolded towel.

B. Rules for the relative topological connection of layers

The fact that the shape of a towel is rectangular dictates some restrictions about the possible topological relations between the layers. First of all, when a towel is held by one of its corners, then, the lowest point of the hanging article corresponds to its not neighbouring corner. So, it is a priori known that the layer with the lowest point covers the diagonal of the towel (in Fig. 5.b it is layer L1). Nevertheless, it is not known if the edges of the lowest corner correspond to the lower or a side edge in an unfolded configuration(Fig. 5.a). Another restriction that the towel imposes is that its shape is convex. So, the closest to the diagonal a layer is, the longer its edges, when it is compared with other layers placed on the same side of the diagonal. For example, in Fig. 5.b layer L3 cannot be placed closer to the diagonal than L2, or L4 cannot be left on the side of the layer L1 where it is currently located.

Additional geometric constraints are provided by the edges connecting adjacent layers. Two layers might have one common edge, they might not have any edge in common or an edge of a layer might coincide with a part of the edge of another layer. In this case the layers are called neighbours (in Fig 6.a L2 and L3 are neighbours, whereas in Fig. 6.b L3 and L4 are neighbours). The first case is rather interesting since its gives a definite topological connection between the two layers with the common edge. The two layers occur from a fold and correspond to neighbouring positions in the unfolded configuration of the towel (in Fig. 6.a L1 is connected to L2 whereas in Fig. 6.b L1 is connected to L2 and L3 and L4 is connected to L5). This common edge is called folding axis(Fig. 6). In addition, if the folding axis is one of the edges that establishes two layers as neighbours in the hanging configuration, then the two layers cannot be at the same side of the towel's diagonal in an unfolded configuration (in Fig. 6.a for layers L2 and L3). This occurs only for layers that start close to grasping point. Actually, if this was not the case, the layer with the folding axis had to extend behind the visible part of the towel and then continue to the neighbour layer. In this case, it would not be possible for the neighbour layer to start from a point close to the grasping point.

Finally, by observing the relations between layers, indicators about the most plausible relative position of two layers are introduced. These indicators are taken into account only when a definite connection between the layers has not been established by the previous rules. So, it is observed that a layer is usually topologically connected, in the unfolded configuration, to the layer and from the side of the layer with which their edges: 1) have the smaller difference in length, 2) are neighbours. As it is shown in Fig. 7.b, these conditions are valid for the layers L3 and L4. An exception is made and these indicators are not taken into account, in configurations like those depicted in Fig. 7. In these cases: 1) the layer with the diagonal is neighbour with another layer (in Fig. 7.b L1 is neighbour with L2) or 2) the layer, with which the layer with the diagonal is connected through a folding axis, completely overlaps it and is neighbour with another layer (in Fig. 7.a L2 completely overlaps L1 and is neighbour with L3). The exception is valid only for the connection of these neighbouring layers and not for the whole configuration.

C. Indicators for the correct final configuration

After the examination of the relative position that the layers could have in an unfolded state, more than one possible

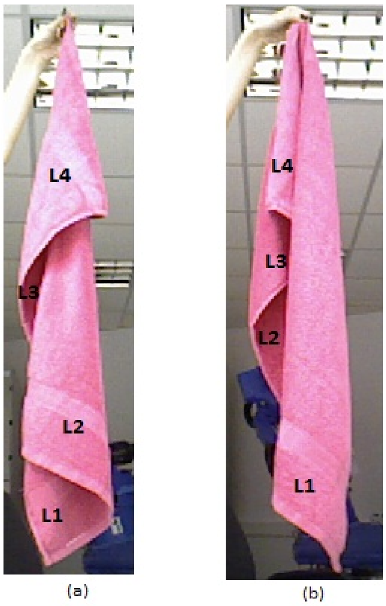

Fig. 7. Configurations excluded from the indicators

configuration might occur. Although there may be a preference to one of them according to the method's indicators, the whole configuration is evaluated in order to achieve better results. Once more, the rules suggested here cannot give a definite result on their own, but combined with the previous indicators they determine the solution. So, one indicator that a configuration is correct is that the smaller edge connected to the grasping point, which probably corresponds to the upper side of the towel, and the smaller edge connected to the towel's lowest hanging point, which probably corresponds to the lower side of the towel, incline towards the same side(Fig. 8.c). In addition, another indicator about the correct configuration of the towel is based on the lowest corner of the towel, when both of its edges are visible (e.g. when the layer which includes this corner is rectangular, like L1 in Fig. 8.a). Actually, the angle that the diagonal, which connects the grasping point with lowest hanging point, creates with the lower edge of the towel is bigger or, in the rare case of a square towel, even with the angle created by the diagonal and side edge of the towel (for convenience the complementary of these corners are calculated as shown in Fig. 8.c). So, according to these angles the lower side of the towel can be found(e.g. edge e1 in Fig. 8.c). If the smaller edge connected to the grasping point, which usually corresponds to the upper edge of the towel, inclines to the same side as the lower edge, then this constitutes an indicator that this configuration is correct.

In Fig. 8, two possible results from the analysis of hanging towel's state in Fig. 8.a are shown. The shapes that occur provide the topological connection of the layers and not the actual shape of the towel. As it is obvious from Fig. 8.a, in Fig. 8.b the result is wrong, whereas in Fig. 8.c correct. The same conclusion occurs from the application of the two indicators for the correct final configuration. In Fig. 8.c edges e1 and e3, which are the smaller edges connected to the lower point of the towel and the grasping point, incline towards the same direction. In addition, angle $\omega 1$, is smaller than $\omega 2$, implying that edge e1 is the lower edge of the towel.

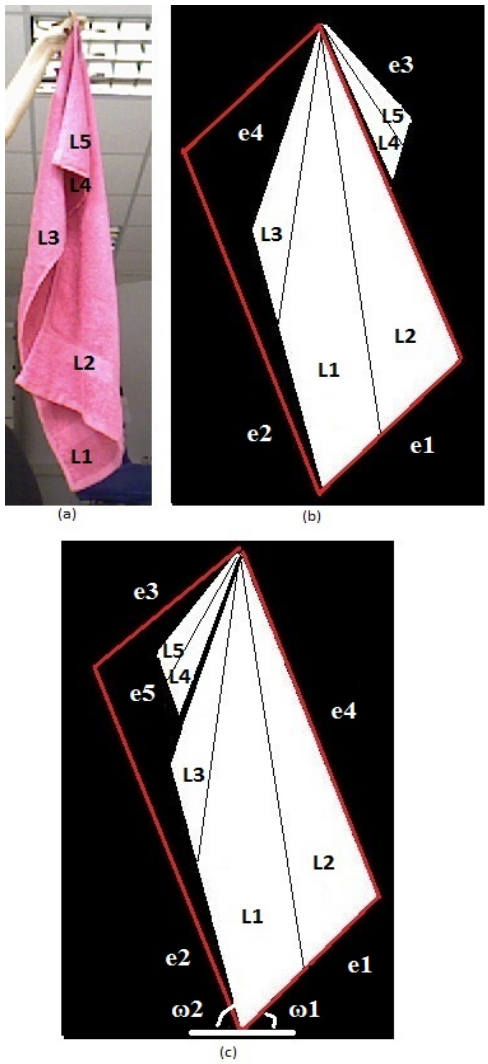

Fig. 8. (a)the towel in a random configuration, (b) a candidate for the layers' topological connection, (c) the correct topological connection of the layers

IV. Experiments

The presented method was tested with 50 different configurations of a hanging towel. For each configuration we obtained several images under slight rotations around the vertical axis. The feature detector was applied on these set of images. In 72% of the cases, the detector failed to detect correctly a few features (an edge could be missing or be split in two creating a false junction, a small extra edge could be created adjacent to a bigger one because of the noise of the 3D data, a junction could be missing). Despite the fact that most of the features were detected correctly, these mistakes in the feature extraction create problems in the detection of layers for the topological analysis(a range sensor with higher resolution and the association of the 3D data with the rgb image are expected to improve the results). Due to these cases,the edges and junctions of the towel were manually supplied in subsequent experiments, so that we may asses the configuration estimation regardless feature detection performance. Correct topological connection of the layers and correspondence with the edges of the towel in an unfolded configuration was achieved for 49/50 configurations, while for one case there was a tie between the correct result and a wrong one. The correctness of the mapping was validated qualitatively.

An example that proves the correctness of the method is shown in Fig. 8. The hanging towel is divided in 5 layers. For Layers L1, L2 and L3 and for L4 and L5, there is a definite topological connection through their folding axes. The fact that L3 and L4 are neighbours and that their edges have small difference in length indicate a possible topological connection between these two layers. Although there is a preference to the combination of the layers depicted in Fig. 8.c, due to the relation between L3 and L4, the combination in Fig 8.b is not excluded. Both of them are evaluated for their final result. As it is already mentioned, the combination depicted in Fig. 8.c satisfies the indications for a correct final topological connection. So, since all the indications agree to it, the topological analysis depicted in Fig, 8.c is considered correct. In addition, according to the indicators, edge e1 is corresponded to the lower edge of the towel, e4 to a side edge, e2 and e5 to a side edge different than the one of e4. Edge e3 corresponds to the upper edge of the towel or to an edge created by a fold close to it. The upper edge of a towel is not always visible to the camera (Fig. 6.a), and since information about the texture of towel, which is different at the outline, is not used, it is not possible to be affirmative that an edge is the upper edge of a towel.

V. Conclusions

The presented method analyses the topology of a hanging towel. The towel, according to its edges and junctions, is decomposed into layers, which are corresponded to a position in an unfolded configuration of the towel. The parts of the towel that are not visible to the camera and the different directions of the layers did not allow facing the problem as a puzzle. So, rules based on the rectangular shape of the towel and on observations of the hanging towel's configurations are introduced. Firstly, the relative position of the layers is examined and then the whole topological connection is evaluated. According to the final result, the edges of the layers are corresponded to the edges of the outline of the towel when it is unfolded.

With the proposed approach, good grasping candidates can be detected for the unfolding of the towel. Even in cases where a preferable grasping point, e.g. a neighbouring corner of the current grasping point, is not visible, the topological analysis provides information about the visible part that is closer to it. So, the appropriate manipulations can be performed in order to make it visible to the camera and grasp it.

For future work, the extraction of edges and junctions might be ameliorated with the use of a higher resolution range sensor and the association of the 3D data with the RGB image of the sensor. In addition, the topological analysis method will be extended to other types of clothing besides the towels. Finally, the manipulations that the robot has to perform in order to grasp or make visible the desired grasping point are planned as future research direction.

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