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A geometric approach to robotic unfolding of garments

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HIGHLIGHTS

- A geometric approach for robotic unfolding of garments is proposed.
- Folds and hemline edges are detected and used as initial grasp points.
- Unfolding is completed through template matching with foldable templates.
- Garment classification is also achieved through template matching.
- Experiments in a variety of garments prove the method's robustness.

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ABSTRACT

This work presents a novel approach to autonomous unfolding of garments by means of a dual arm robotic manipulator. The proposed approach is based on the observation that a garment can be brought to an approximately planar configuration if it is held by two points on its outline. This step facilitates the detection of another set of points that when grasped the garment will naturally unfold. A robust method for successively detecting such boundary points on images of garments hanging from a single point was developed. The manipulated garment is then laid on a flat surface and matched to a set of foldable templates using shape analysis techniques. Using the established correspondences with the template's landmark points the garment is re-grasped by such two points that it will naturally unfold in a spread out configuration. The adopted framework has been experimentally evaluated using a dual industrial manipulator and a variety of garments. The produced results indicate the feasibility and robustness of the proposed approach.

1. Introduction

Despite recent advances in robotics research, autonomous handling of deformable objects such as real garments still remains very challenging. One of the most difficult tasks is bringing the garments into a spread out configuration, i.e. unfolding. Even in the highly automated garment manufacturing industry this is the only step where humans are employed. Only a few recent studies address autonomous garment unfolding. The majority of them is relying on heuristic techniques, ad hoc rules or are restricted to simple garments such as towels. In summary, in the literature, unfolding is achieved by means of one of the following heuristics:

(a) Selection of appropriate grasping points that when grasped by two hands the garment is unfolded by gravity without the need for any intermediate rehandling. In the simple case of towel unfolding, neighbouring corner points are adequate [1], whereas for other garments more sophisticated techniques are required to infer the current configuration from images and thus select the appropriate grasping points [2–7].

(b) A two step approach where the garment is initially held by two outline points resulting in a flat configuration on a table and then picking up from a set of points to completely unfold it [8–10].

(c) Instead of grasping two outline points the iterative regrasping of the lowest hanging point also results in a flat configuration thus facilitating unfolding [11,12].

(d) A few techniques try to unfold the garment without lifting it from the table (i.e. spreading it) by pulling it [13] or by an origami like unfolding process [14].

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The first group of methods imitates the humans performing the task [1,4,5,7]. Nevertheless the tracking of the configuration of the garment (i.e. map points of the hanging garment to those of the unfolded one) is necessary to localize grasping points, which constitutes a very challenging task. The third approach is the simplest and requires minimum vision but has the limitation that a very large working space is needed for handling real garments [11,12]. The fourth approach requires that the garment is just wrinkled [13] or is folded but flat [14].

For the above reasons our approach uses the second heuristic [8–10], adopting the assumption that holding a garment by two points on its outline can bring it into an approximately planar configuration. Although the garment remains folded, its flat configuration facilitates the modelling and manipulation in order to locate suitable re-grasping points for unfolding. The proposed approach, similarly to [8], breaks down the unfolding task to three subsequent subtasks: (a) rehandling, where a method for extracting outline grasping points of a hanging garment is applied, (b) modelling, where the folded garment is modelled using unfolded templates that are matched to its contour, and (c) shaping, where based on the extracted model suitable re-grasping points are selected for unfolding. A robust method for extracting outline grasping points is proposed based on depth information. This is in contrast to [8,9] where outline detection is based on detection of shadows on the intensity image thus making the method sensitive to the environment. Moreover, instead of employing ad hoc rules as in [9] to analyse the resulting configuration, we propose a generic template matching technique that is able to work with folded shapes presenting the best match to the half-folded garment. This allows us to easily include a large variety of garments by just introducing the corresponding template that approximates their shape outline. This enables the selection of the re-grasping points for unfolding based on the entire model of the folded garment and not only on distinct features like those employed in [10], increasing the confidence on the results. Compared with methods using the lowest hanging point heuristic [11,12,7], our approach allows efficient handling of real-sized garments by robots with limited workspaces.

This paper is organized as follows. Section 2 presents related work while in Section 3 the proposed approach for robotic unfolding is analysed in detail. In Section 4 the experimental results are demonstrated and discussed and the paper concludes with Section 5.

2. Related work

The first category of unfolding techniques mentioned in the previous section involves grasping the garment by two points that lead to natural unfolding of the clothing article by gravity without any intermediate rehandling. An example of such work is described in [1] where Maitin-Shepard et al. address robotic unfolding of towels by extracting geometric cues from stereo images in order to detect corner points for grasping. In their work, border points are detected on the hanging cloth using curvature features. Then, candidate corner points are selected for grasping using a RANSAC-based algorithm that fits corners to the estimated border points. The selected corners are grasped in order to bring the manipulated towel to a spread out configuration before folding. Moreover, Yamazaki [2,3] selects simultaneously two grasp points that lead to natural unfolding on a garment randomly placed on a table. The garment's shape is described using hem elements extracted from a range image while the grasp points are selected based on global shape similarity with a list of training data.

Other methods, included in the first category, use pose or configuration inference techniques to achieve unfolding. Kita et al. [4] consider a mass–spring model to simulate a T-shirt's silhouette when hanging from a point at its outline. The simulated models are fit to the image of a true hanging garment allowing to localize and subsequently grasp a desired point. Li et al. [5] reconstruct a smooth 3D model of the garment and, using a feature extraction and matching scheme, match the real article to the most similar model in a database. Since its configuration is known, the robot can bring the garment in an unfolded state by iteratively grasping it from predefined points according to its type [6]. The type of the garment, as in [4], is known a priori. Instead of fitting a 3D model Doumanoglou et al. [7] use Random Decision Forests for garments recognition and Hough Forests for the estimation and grasping of two predefined points according to the garment's type. The garment's lowest hanging point is used as the initial grasping point in order to limit the number of possible configurations. Their approach relies on the acquisition of a huge training set of garments under various configurations and its annotation with desirable grasping point positions (hanging corner points).

The second category of unfolding methods, which is the most similar to our approach, includes the work of Hamajiama et al. [8,9] and Kaneko et al. [10]. In their work, the unfolding task is divided into three subtasks: rehandling, classifying, and shaping. During rehandling [8] the garment is grasped by two hemline points in order to facilitate classification and shaping. The detection of hemlines, is based on the appearance of shadows at the vicinity of garment's outline while hanging. As a contingency plan in case no hemline is detected, the lowest hanging point is selected. In that study, three garment types (towel, shirt and pants) are considered, whereas the classification and shaping subtasks are not addressed. As reported in that work the proposed approach is not robust to changes of the environmental conditions. The classification subtask is addressed in [9], by means of geometric features extracted by the rehandled garment and the application of ad hoc rules. The same three garment types are considered and a 90.6% average success rate is reported for classification. However, the presented classification approach is using manually defined models for the possible configurations of the three garment types after rehandling and different set of features are extracted for each model. Thus, their approach is difficult to generalize to different garment types or sensor setups. Kaneko et al. [10] adopts the rehandling and classifying approaches of [8] and [9] and proposes a method for performing the shaping task by selecting appropriate grasping points for bringing the garment to an unfolded configuration. The method is based on the detection of corners and 'stick-out' regions extracted using a line-approximated image. The line-approximated image is estimated by differentiating three images of the garment acquired under different orientations of the illumination, in order to accentuate the edges of the overlapping parts. A 96% average success rate is reported for the manual unfolding of the rehandled garment using the estimated grasping points. However, the above success rate is achieved after repeating the proposed procedure in case of failure, until the garment is finally unfolded.

The third category of unfolding techniques uses a heuristic approach to achieve unfolding which is based on the selection of the lowest hanging point and was introduced by Osawa et al. [11]. Namely, the garment is hanged by an arbitrary point and the lowest hanging point is initially grasped. If the procedure is repeated the garment will result in spread out configuration as held by two arms. The manipulated garments are then classified to the most similar type by evaluating the covariance between their images and a set of templates. The same heuristic is used by Cusumano et al. [12] for bringing children clothes to desired configuration. The method uses a Hidden Markov Model in order to track the garment's configuration during handling with the goal of recognizing the specific article, by matching its outline with existing templates. The lowest point heuristic becomes problematic with large