CHAPTER X

Future Trends in Perception and Manipulation for Unfolding and Folding Garments

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This paper presents current approaches for robotic garment folding-oriented 3D deformable object perception and manipulation. A major portion of these approaches are based on 3D perception algorithms that match garments to a model, and are thus model-based. They require a full view of an extended garment, in order to then apply a preprogrammed folding sequence. Other approaches are based on 3D manipulation algorithms that are focused on modifying the pose of the garment, also oriented at matching it with a model. We present our own garment-agnostic algorithm, which requires no model to unfold clothes, and works using a single view from an RGB-D sensor. The unfolding algorithm also has been validated through experiments using a garment dataset of RGB-D sensor data, and additional validation with a humanoid robot platform. Finally, conclusions regarding the current state of the art and on the future trends of these research lines are discussed.

1 Introduction

Every day, humans encounter garment manipulation tasks in both domestic (e.g. laundry) and industrial (e.g. garment manufacturing) environments. A growing need exists for automated solutions to help us to perform these tasks, as they are tedious and repetitive. Additionally, another critical factor involved in this increase in demand is the increasing aging of the world population. This is because of the decrease in mobility associated with elder age. Currently, the only existing automated solutions are bulky and expensive, as can be seen in Fig. 1 (right). They are intended to be used in an industrial environment, so they are not suitable for domestic use.

Fig. 1. Current clothes folding solutions available for garment folding. On the left, human workers folding clothes in a textile factory. On the right, an automated solution available in the market, manufactured by Texgraff©.

Robots, more specifically, humanoid robots, arise as a sensible choice. Humanoid robots are designed to work in human environments and to have human-like locomotion and manipulation capabilities. However, working with garments involves deformable 3D objects. This not a trivial task for robots. Modeling is especially complex due to the almost infinite number of poses into which a textile article can be brought. The situation becomes even more complex in the presence of several garments, as they can easily be entangled, increasing the amount of occlusions and complicating the recognition of each individual garment using 2D or 3D computer vision techniques. Bringing garments to a desired configuration from an arbitrary initial pose is a very challenging issue.

The way humans perform laundry has inspired most of the works that can be found throughout robotic literature. The human pipeline usually begins with the extraction of a garment from a washing or drying machine. Garments are placed on a pile, from where deformable 3D object perception allows them to be picked up one at a time, initiating an iterative sequence. Deformable 3D object manipulation is used to extend and flatten the garment, either in the air, or with the help of a flat surface such as a table. The extended garment is then classified and fit into a garment model according to its category. Finally, the garment model is used to execute a preprogrammed folding sequence on the garment. Once a garment is folded, the next garment is picked up from the pile.

This paper focuses on past and current approaches in robotic garment perception and manipulation, and on exploring the robotic trends of the future.

2 State of the Art

One of the main contributors within the existing model-based work has been the computer graphics community (Chen, Yin, & Su, 2009). Model-based approaches focus on classifying garments in categories according to a model when the garments are grasped or extended on a flat surface.

Kita et al. use deformable models to estimate the state of hanging clothes based on 3D observed data (Y. Kita, Saito, & Kita, 2004)(Yasuyo Kita, Ueshiba, Neo, & Kita, 2009). Several candidate shapes are generated through physical simulations of hanging clothes. They are later compared to the observed garment data. Further deformation of these candidate shapes is allowed to make the model fit the data more accurately. The shape which is more consistent with the data is finally selected.

Miller et al. present a method for modeling garments once they are extended on a flat surface in (Miller, Fritz, Darrell, & Abbeel, 2011). Parameterized shapes are used as model, where some parameters are fit from garment data and other parameters are computed using the fit parameters. Each garment category requires a different model, and parameters allow each model to adapt to the garment shape within each category.

A method for classifying and estimating the poses of deformable objects is presented in (Li et al., 2015). It consists in creating a training set of deformable objects by off-line simulation of different garments, extracting depth images from different points of view. A codebook is built for a set of different poses of each deformable object. With this codebook, classifying deformable objects on different categories and estimating their current pose is possible, for later regrasping or folding the garment.

Clothing article manipulation is the other main approach to garment folding. Osawa et al. propose in (Osawa, Seki, & Kamiya, 2006) a method to unfold garments in order to classify them. It consists in alternatively regrasping clothing from the lowest point and attempting to expand them using a two-arm manipulator.

The method introduced by Cusumano-Towner et al. in (Cusumano-Towner, Singh, Miller, O'Brien, & Abbeel, 2011) allows a bi-manipulator robot to identify a clothing article, estimate its current state and achieve a desired configuration, generalizing to previously unseen garments. For that purpose, the robot uses a Hidden Markov Model (HMM) throughout a sequence of manipulations and observations, in conjunction with a relaxation of a strain-limiting finite element model for cloth simulation that can be solved via convex optimization.

In (Li et al., 2015) Li presents a method for unfolding deformable objects with a bi-manipulator robot. With this method, the robot is capable of taking a clothing article from an unknown state to a known state by iterative regrasping, detecting the most suitable grasping points in each state to achieve its goal. For locating the most suitable grasping points, the 3D point cloud obtained by the robot is matched to the mesh model that incorporates the information about the best regions to grasp in order to unfold the garment.

In (Willimon, Birchfield, & Walker, 2011) Willimon et al. use several features obtained from a depth image, such as peak regions and corners location, to determine the location and orientation of points where the robot later interacts with the garment.

CloPeMa[1] is a recent EU-FP7 research project (2012-2015) whose objective is to advance the state of the art in perception and manipulation of fabric, textiles and garments. As part of the CloPeMa project, a method to detect single folds has been presented by Mariolis et al. in (Mariolis & Malassiotis, 2013)(Mariolis & Malassiotis, 2015). In order to detect such folds, first, a dataset of unfolded clothes templates is built. These templates are later used to perform a shape matching between the folded garment shape, obtained by the camera, and the unfolded garment model. This process is iterative, and the initial results are served as feedback to adapt the model for a better fit. Stria et al. propose in (Stria, Pruša, Hlaváč, Wagner, & Petrik, 2014)(Stria, Pruša, & Hlaváč, 2014) a polygon-based model for clothes configuration recognition using the estimated position of the most important landmarks in the clothing article. Once identified, these landmarks can be used for automated folding using a robotic manipulator. The clothes contour is extracted from an RGB image and processed using a modified grab-cut algorithm, and dynamic programming methods are used to fit it to the polygonal model. Doumanoglou et al. follow in (Doumanoglou, Kargakos, Kim, & Malassiotis, 2014) an approach based on Active Random Forests in order to recognize clothing articles from depth images. The classifier allows the robot to perform actions to collect extra information in order to disambiguate the current hypotheses, such as changing the viewpoint.

[1] http://www.clopema.eu/

3 A Garment-Agnostic Approach to Unfolding

Existing work found in the literature has focused in garment recognition and modeling once the garment is extended, as well as in developing folding algorithms using those models. For this reason, our work has focused on the step previous to having an unfolded garment, which is how to unfold a clothing article that has been picked up from a pile of clothes and is placed on a flat surface. The original algorithm has been recently published in (Estevez, Victores, Morante, & Balaguer, 2016). Fig. 2 depicts the outline of the algorithm, which uses a single RGB-D sensor view for rapid processing of the deformable 3D object perception algorithm.

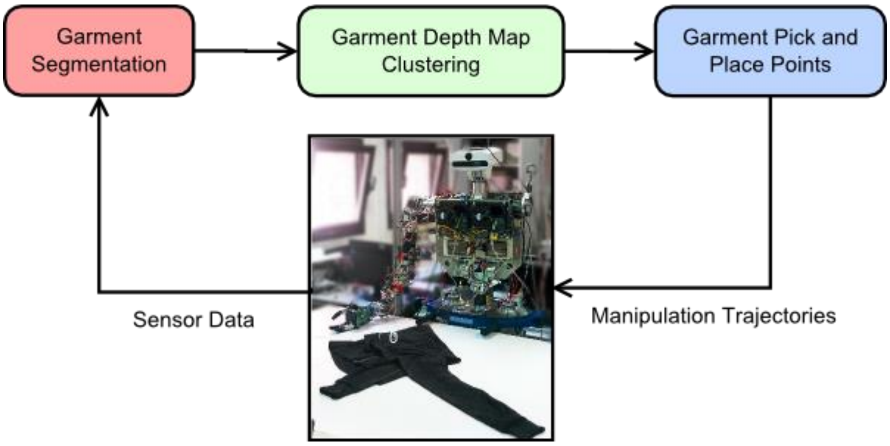

Fig. 2. Pipeline of the Garment-Agnostic Approach to Unfolding algorithm.

The depth information provided by the RGB-D sensor is converted into a grayscale image. Garment Segmentation is performed in the HSV space, and then Garment Depth Map Clustering is performed using a watershed algorithm. This algorithm provides us with labeled regions, each having a different height. In this labeled image, we assume that the highest height region belongs to the fold. Starting on this region, and ending in the garment border, tentative paths are created by the Garment Pick and Place Points stage, in several directions to analyze the height profile. For each profile, a *bumpiness* value B is computed as in Equation (1).

$$B = \sum_{i=1}^{n} \left| path(i) - path(i-1) \right| \qquad (1)$$

The lowest one is selected as the unfolding direction. A final extension on this line is performed to create a pick point on the fold border, and a place point outside the garment. Experiments for evaluation of the algorithm were performed over a dataset of RGB-D sensor data, and additional validation with a humanoid robot platform as seen in Fig. 3.

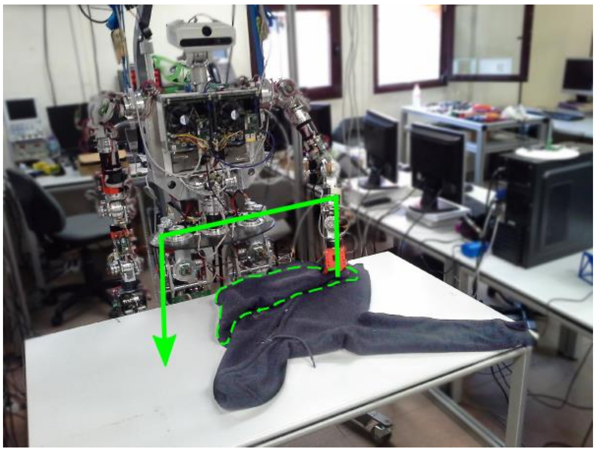

Fig. 3. Humanoid robotics clothes folding scenario. The clothes are placed on a flat white table, while a RGB-D sensor is positioned on the top.

4 Conclusions and Future Work

In this paper we have reviewed several model-based approaches, and also garment manipulation-based approaches for garments, in the context of deformable 3D object perception and manipulation. Finally, a model-free garment-agnostic algorithm to unfold clothes was presented. Results show that our approach to garment-agnostic unfolding is promising to be included in a complete pipeline of clothes folding. The main contribution of our work is its analysis of the garment not dependent of a prior model. Using only depth information for detecting overlapped regions (except for Garment Segmentation, where other algorithms could be used), as opposed to using RGB images, makes our algorithm independent of the colors and patterns present in the garments.

Our future lines of research include implementing a pre-processing stage in which a perspective transformation is performed (to perceive the garment as if a bird's eye point of view were used), using multiple views of the deformable 3D object (e.g. KinFu with GPU acceleration), and performing large-scale experiments in perception and manipulation with large datasets and prolonged physical trials (e.g. with industrial manipulators).

In a broader sense, we expect the robotics community to aim its efforts towards perceiving and manipulating deformable 3D objects. They represent a grand portion of our everyday life whether in domestic, office, or outdoor environments. While our first approaches have been aimed at this tedious household and industrial chore, the long term goal of this work is to allow robots to perform any kind task that requires addressing the difficulties of perceiving and manipulating these objects.

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