Requirement scoping of a biologically inspired robotic end-effector to grasp deformable material

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I. Introduction

This work presents a concise review of devices designed to manipulate fabric followed by a brief human study as motivation to develop a novel robotic end-effector for fabric grasping. This discussion then results in a described scope for efficiently grasping clothing in an anthropomorphic manner along with a proposed device which can fulfil these requirements while remaining a mechanically simplistic system.

Robots are fast becoming part of our daily lives, assisting us in a variety of applications. Rapid integration of autonomous agents into our routines has led to the exploration of novel research applications in robotics. One such area that has seen a recent resurgence is in the manipulation of deformable objects such as textiles. An action which is simple to humans, but has shown to be more challenging for an autonomous agent. A simple fabric grasping action alone can be influenced by a multitude of parameters such as the end-effector utilized, the environment and the state of the grasping target. Analyzing grasping actions has been a widely discussed topic throughout research regarding any autonomous manipulation task. The argument is made that various works designing end-effectors, examples displayed in 2, for deformable manipulation have frequently referenced human-like grasping actions. However, there has been limited reference to anthropomorphic grasping definitions within the literature from a hand-oriented perspective. Investigations into this area could observe capabilities taken from human-based motions which can provide insight and scope into novel designs. Taxonomies focused on the human grasp[3][2], and the various parameters that differentiate them were utilized for discriminators. Research that describes in-hand dexterous manipulation[1] is also applicable to actions such as grasp motions or haptic exploration.

With the conformity of fabric to the grasp action, a majority of end-effectors will be capable of grasping material in generic scenarios. However, edge cases, including when the fabric presents itself in a levelled state, make this initial grasp a more complicated task. Approaches that take into account and exploit the environmental constraints present to assist with grasping have been seen throughout the literature[4][11].

Fig. 1: Examples of Bio-mimetic Grasping

In this work, we define arbitrary grasping as the ability to grasp flattened fabric on a level surface from an array of wrist positions and orientations. Previous works have required methods which approach the target garment with limited ranges of these parameters. Arbitrary grasping can be considered biomimetic as a grasping motion; the action will involve dragging a finger across a surface producing a protrusion in the fabric's body for the effector to grasp. See 1 as an example.

To the authors' current knowledge, no work exists that investigated the avenue of arbitrary grasping, reducing the impact of motion planning and grasp point localization on a pick and place task applied in deformable object manipulation. Such an approach could be considered anthropomorphic. Humans give little thought to the initial grasp point in manipulation tasks. This assumption is made from a small observatory exercise completed in late 2018 at the University of Canberra. It was from this observation where the concept of arbitrary grasping was first noted.

In this exercise, participants were asked to sort clothing from a jumbled heap into categories dependant on their physical or utilization properties. While asking participants to conduct this study, we observed that very little consideration

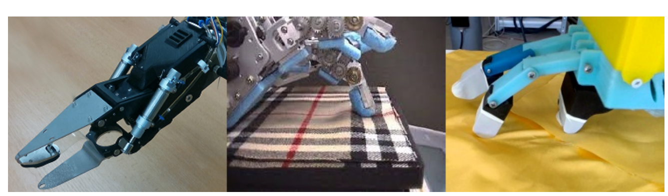

Fig. 2: Effectors applied in deformable manipulation

(a) Observatory Exercise Snapshot A

(b) Observatory Exercise Snapshot B

(c) Observatory Exercise Snapshot C

Fig. 3: Frames from clothing grasping observatory exercise

was given to the initial grasping parameters of the garment with participant focus being on re-grasping strategies if required for the manipulation task. Examples images from the exercise can be seen in 3.

II. Grippers Applied in Deformable Manipulation

Various specialized robotic gripping devices have been created for deformable manipulation purposes. These devices were designed to be applied in several settings. Tasks such as extracting garments from a pile [7], folding laundry [6], exploring a garments body for haptic information [14] or grasping fabric in a flat state [4] were explored.

The need for this work, in part, was inspired by the two broad techniques seen when grasping fabric in a flat state. This flattened grasping approach presents an issue of how to navigate and account for the surface that the fabric presents itself on. A biomimetic environmental constraint grasping action[5][8][4] utilizes fingers to create deformities on the body of the fabric which can then be grasped as they protrude from the surface. Alternatively, an insertion approach applied by Le et al.[7] where a small fingernail like appendage will insert itself beneath the fabric on the surface, followed by a clamp grasp on either side of the fabric's body. Each described technique has limitations, in all the work describing biomimetic grasping motions, approaches from the arm to the target surface could only come from a linear horizontal or vertical direction. In contrast, an insertion approach could come from a more diverse range of angles, an edge where the fabric and surface bodies meet is required for such a grasping action to take place. A consideration when utilizing a biomimetic grasp in this task was presented by Koustoumpardis et al. [4]. As the fingertip experienced change on the contact surface, in this case, from the environment surface where the fabric is presented to the fabric itself, the force required to move along the surface while in contact experiences a significant decrease.

Other grippers were designed to or trace or traverse over the bodies of garments. Sahari et al.[9] where three separate effectors were designed and traced over the body of a garment. The first two effectors were simple clamp effectors with the difference being roller fingertips on the end of the roller end-effector. The inchworm effector was unique in the design aspect as there were two clamp grippers parallel with one of the effectors able to move in a perpendicular direction bringing the clamp effectors closer together, moving in an inchworm-like fashion. This work was the primary example of an effector directly tracing cloth, allowing the fabric to slide between fingers.

Shibata et al.[10] presented an effector with similarities to the inchworm device that consisted of two clamps on a long prismatic actuator. This effector could grasp and unfold garments placed on a surface. The grasp itself was created a rubbing motion to create wrinkles. Once grasped, an unfolding motion can be created by running each clamp effector across the prismatic joint in opposing directions. Such an action could also be considered a bimanual manipulation task with the multiple grasp points and the distance that can occur between them. Both features of an insertion grasp and a biomimetic grasping action were present in this work.

A minority of effectors designed for deformable manipulation have presented the ability to perform in hand dexterous haptic exploratory actions to both determine grasping success and classify grasped objects. The NAIST M2S OpenHand [13][14] and the CloPeMa gripper [7][12] produced precision grasp type effectors with embedded haptic sensors for these aforementioned tasks. Drigalski et al.[14] utilized triaxial force sensors to detect force slippage and classify a variety of deformable household materials ranging from rubber gloves to garments. The work of CloPeMa utilized a multimodal tactile sensor made up of a capacitive pressure sensor array, microphone and ambient light sensor. A rubbing motion performed by the end effector would perform a linear haptic exploration motion to be interpreted by the microphone and pressure array. The ambient light sensor was used to validate grasping success.

The works summarized here present an opportunity to scope a subset of human-centric motions applicable to deformable manipulation, in a summarizing statement after observing these works; we define an ideal set of human motions for grasping deformable objects broadly as

- Arbitrary Bio-mimetic dragging grasping ability.
- A generic precision grasp technique.
- Capability to perform haptic exploration.

To this end, we look towards the development of a novel end-effector which can perform these capabilities mentioned above. A drawback of previous effectors applied in deformable manipulation could not perform all three of these skills.

III. Discussion

With the insights provided in this work, we have begun a development process for a novel end-effector explicitly designed for fabric manipulation. Unlike previous effectors designed for fabric manipulation, this device can perform a complete set of actions allowing it to grasp the fabric in almost any scenario and perform haptic exploration of held garments. The device is based on the lateral grasp, where the grasp points of contact are between the adducted thumb and the side of the index finger. A factor that makes this grasp unique is the elements of power and precision grasp features, allowing the effector to retain in-hand dexterous capability while able to perform grasps with a stronger force. A thumb effector is present while a static base plate represents the index finger component.

We perform the task described in Feix et al.[3] of sub-categorization for grasps adapted to specific purposes, In this case, the lateral grasp where we define the grasps of Lateral Extension Grasp and Lateral Flexion Grasp as shown in 4. While in the flexion state the gripper can perform arbitrary grasping moving into a precision type grasp and while in the extension state the effector can apply actions such as haptic exploration and hold the clothing in what can be considered an intermediate state as defined above with elements of power and precision grasping.

Specifically, it also offers two capabilities which are not met in the literature. This effector can perform arbitrary grasping while in contact with the surface. Meaning in the scenario where the static plate is pressed against a flattened fabric on a level surface, the thumb effector can execute a biomimetic grasp. The arbitrary definition comes from the in-built capability to perform this action on different points of the static plate. Resulting in a range of orientations and positions where the effector can perform this action. Based on the literature reviewed, we argue that this capability, arbitrary grasping in deformable manipulation, is novel and warrants further exploration.

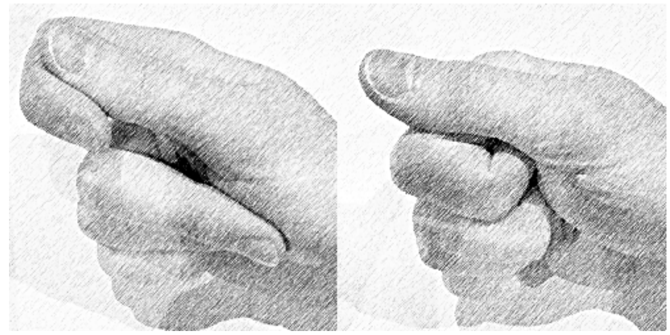

Fig. 4: Sub-categories of the lateral grasp

References

[1] Ian M Bullock, Raymond R Ma, and Aaron M Dollar. "A hand-centric classification of human and robot dexterous manipulation". In: *IEEE transactions on Haptics* 6.2 (2012), pp. 129–144.

[2] Mark R Cutkosky and Robert D Howe. "Human grasp choice and robotic grasp analysis". In: *Dextrous robot hands*. Springer, 1990, pp. 5–31.

[3] Thomas Feix et al. "The grasp taxonomy of human grasp types". In: *IEEE Transactions on Human-Machine Systems* 46.1 (2015), pp. 66–77.

[4] Panagiotis N Koustoumpardis, Kostas X Nastos, and Nikos A Aspragathos. "Underactuated 3-finger robotic gripper for grasping fabrics". In: *2014 23rd International Conference on Robotics in Alpe-Adria-Danube Region (RAAD)*. IEEE. 2014, pp. 1–8.

[5] Panagiotis Koustoumpardis, Sotiris Smyrnis, and Nikos Aspragathos. "A 3-Finger Robotic Gripper for Grasping Fabrics Based on Cams-Followers Mechanism". In: June 2018, pp. 612–620. ISBN: 978-3-319-61275-1.

[6] Loan Le et al. "Application of a biphasic actuator in the design of the CloPeMa robot gripper". In: *Journal of Mechanisms and Robotics* 7.1 (2015), p. 011011. ISSN: 1942-4302.

[7] Loan Le et al. "Development and analysis of a new specialized gripper mechanism for garment handling". In: *ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. American Society of Mechanical Engineers. 2013, V06BT07A013–V06BT07A013.

[8] Eiichi Ono, Hishao Ichijou, and Noborou Aisaka. "Robot hand for handling cloth". In: *Fifth International Conference on Advanced Robotics' Robots in Unstructured Environments*. IEEE. 1991, pp. 769–774.

[9] Khairul Salleh Mohamed Sahari et al. "Edge tracing manipulation of clothes based on different gripper types". In: *Journal of Computer Science* 6.8 (2010), pp. 872–879.

[10] Mizuho Shibata and Shinichi Hirai. "Fabric manipulation utilizing contacts with the environment". In: *2012 IEEE International Conference on Automation Science and Engineering (CASE)*. IEEE. 2012, pp. 442–447.

[11] Mizuho Shibata, Tsuyoshi Ota, and Shinichi Hirai. "Wiping motion for deformable object handling". In: *2009 IEEE International Conference on Robotics and Automation*. IEEE. 2009, pp. 134–139.

[12] Michal Jilich Thuy-Hong-Loan Le et al. "On the development of a specialized flexible gripper for garment handling". In: *Journal of Automation and Control Engineering Vol* 1.3 (2013).

[13] Felix Von Drigalski et al. "NAIST Openhand M2S: A Versatile Two-Finger Gripper Adapted for Pulling and Tucking Textile". In: *2017 First IEEE International Conference on Robotic Computing (IRC)*. IEEE. 2017, pp. 117–122.

[14] Felix Von Drigalski et al. "Textile identification using fingertip motion and 3D force sensors in an open-source gripper". In: *2017 IEEE International Conference on Robotics and Biomimetics (ROBIO)*. IEEE. 2017, pp. 424–429.