On the Development of a Specialized Flexible Gripper for Garment Handling

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***Abstract*—In this paper, we discuss ongoing work on the development of a new griper for garments handling and manipulation tasks. We analyze the specificity of the application determining the requirements for the design and functioning of the grasping system. Textiles do not have a stable shape and cannot be manipulated on the basis of a priori geometric knowledge. Therefore, the grasping task cannot be executed without exploring the material and the environment. This is to be achieved by a vision system, which is part of the robotic work cell, in combination with tactile sensors embedded in the fingertips of the gripper. A possible design for the gripper mechanism is outlined and open research and design problems are identified.**

***Index Terms*—grasping, gripper, fabric, garment handling, tactile exploration**

I. INTRODUCTION

Today robotic grippers are widely used for different tasks including assembling, machining, manipulation, and packaging. The main objective of the work addressed in this paper is to design and develop a gripper with dexterity for garment manipulation. This task is part of the CloPeMa European project creating a robot system for automated handling of clothing and other textile items. The envisioned gripper solution is a simple and efficient design leading to a commercially viable device. To meet the demands of a wide range of garment-handling tasks, the gripper should be robust and resistant and at the same time simple, dexterous, and low cost. Autonomous manipulation of limp material in unknown environment requires real-time planning based on continuous acquisition of necessary information from various sources. Environment representation is provided by a vision system able to identify 3D features from 2D scene images. However, to accelerate the processing of data it is necessary to reduce image resolution. This decreases the accuracy of the available description of the environment. The impossibility to guarantee precise knowledge about the positions of the handled objects and the support surface, or about the material properties, is a key determining factor in the formulation of the design specifications of the gripper and its operation.

Thus, it is necessary to ensure a sufficiently large stroke, as well as an ability to flexibly adapt to the hard working surface.

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Moreover, the lack of certainty means that feedback from tactile sensing must be used to correct positioning inaccuracies between the gripper and the manipulated object and to precisely control the applied force in order to avoid either damaging or letting loose of the grasped object. Furthermore, tactile and other sensing must be used to determine the material properties relevant to the task. Therefore, the design must incorporate well placed sensors, and, crucially, has to endow the gripper with a mechanical capability for finger and hand-movements for tactile exploration. This human-like hand-motion ability, going beyond grasping, is a novel and distinctive feature of the developed grasping system.

II. STATE OF THE ART

This section briefly reviews the technical literature in three relevant areas: grasping and tactile-exploration capabilities of the human hand, existing solutions for grasping fabrics, and work relevant to determining the force required when handling garments.

A. Human-Hand Grasps and Haptic Exploration

Humans are remarkably successful at haptically identifying and learning about objects. There has been extensive research on the variety of hand gestures in object exploration and handling [1], [2]. There have been efforts to classify the motions of the hand and the information that can be obtained from them. Cutkosky and Howe presented taxonomy of grasps, in which grasping actions are classified according to their function. The relation between dexterity, power, and object size is also discussed. It is shown that the smaller the object size the more precise the grasp is, especially for the thumb-index finger grasps [3]. Studying haptic understanding, Klatzky and Lederman [4] systematized the knowledge about objects obtained through hand manipulation. They listed the different object attributes that can be recognized by each haptic exploration procedure.

Medical hand prostheses or fully anthropomorphic robot grippers have good grasping performance [5]-[7]. They have highly complex mechanical structures and control strategies. However, when the objective is efficient handling, rather than a convincing mimicry of human movements, such complexity may be redundant.

A good example for minimizing unnecessary complexity is the gripper designed and prototyped by Emantaev [8]. It is an anthropomorphic under-actuated

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hand with fingers moved by tendons and only three actuators. The main structure of the hand is a rubber sheet with the approximate shape of an opened human hand, with the rigid-mechanism part simply glued in a way allowing the intended movements. The simplified design and the economical choice of materials have resulted in a major reduction of production costs compared to artificial hands with comparable grasping dexterity.

B. Grasping of Fabrics

A gripper is a fundamental component in the robotic work cell. Among the currently available market-ready industrial grippers there exist many products suitable for handling rigid objects. In contrast, the handling of non-rigid materials, such as fabrics, remains a challenge faced more in academic research than in industrial practice. Currently used grippers, designed for fabric handling, are usually based on air-jet, vacuum, needle, or adhesive grasping methods. Mainstream research in this area has tried to develop robot work cells for the garment and shoe industries [9]-[12].

The recently completed European project Leapfrog[1] develops and implements new ways of optimal fabric preparation for clothing production, automated garment manufacture, and supply chain integration. Part of the work is on the design of novel robotic handling tools. A combination of traditional and some alternative fabric grasping devices are used; a reconfigurable hanger is mounted on an adaptive gripper. Fabrics are lifted from the cutting table using high-airflow suction applied by the gripper, hanged with clamping pins, and then moved to the sewing machines.

In an ongoing project of UC Berkeley and Willow Garage, the robot PR2 can pick a towel from a heap, and then flatten and fold it on a table [13]. The gripper is equipped with pressure-array sensors and a 3-axis accelerometer. The robot needs as much as 25 minutes to pick up, fold, and stack a towel. For a complex garment, the time would be significantly longer, as it must include the selection of the gripping points as well as motion planning. Moreover, PR2 requires a special table with a soft monochrome surface to perform its work.

The two-finger adaptive gripper of Robotiq [14] can perform three types of grasps: parallel grip, encompassing grip, and inside pick. With high payload to weight ratio it is a good candidate for many robotic applications. However, to identify and classify garments, we need other movements that have not been implemented in this gripper. For example, the lateral exploratory movement [4] plays an important role in learning about the contact surface, and thus provides information of high significance for the system's cognitive process.

C. Grasping Forces

The contact forces exerted during touching, gripping, and grasping, have been studied for a couple decades [15], [16]. However, because of the interdisciplinary nature of this kind of complex experimental research, it remains difficult to find abundant and relevant quantitative data.

In a series of experiments by Kargov et al. [17], a cylindrical object is held with a power grasp and the contact forces are measured at 20 predefined positions. During this experiment, three upper-limb-deficient persons used a System-Electro-Hand™ with a maximum gripping force of 90 N at the fingertips. Another five subjects used a Sensor-hand™. The forces at the fingertips of the four hands: human hand, adaptive prosthesis, System-electro-hand™, and Sensor-hand™ are 6.3 N, 9.9 N, 17.3 N and 24.9 N, respectively.

Most of the research in this area has been focused on the grasping of rigid objects. There is a paucity of information regarding the forces used for the handling of non-rigid materials like fabrics. Estimating the required contact force, and thus obtaining a better quantitative description of the robot task, is part of the research objectives of the work reported in this paper.

III. Task Description

A. Unknown Working Environment:

In the envisioned application scenario, the task is performed by a two-arm industrial robot. It grasps and lifts a garment from a pile lying on a rigid surface. The fact that the garment heap can be placed on any hard surface requires a highly adaptive gripper able to avoid damage while in contact.

Due to the diversity of garments and surfaces, working environment is unpredictable. The unstable shape of garments required real-time data acquisition and processing for recognizing the actual shape and position. Since garments are tangled in the heap, applied gripping and lifting forces values increase dramatically in comparison to their static weight. Estimating the variable load of garments picked from heaps is necessary to estimate the appropriate picking forces. Experiments with representative heap are performed to obtain some indication about the force range.

Realistic technical limitations on the sensing and vision systems must be taken into account: the more precise perception is, the more time it consumes. To optimize the operation of the robot, a reasonable compromise needs to be found between high camera resolution and high processing speed.

B. Handling Task

The grasped piece of clothing is recognized and moved to a defined position. The challenge of the task is how to pick the piece at the right point so that the robot is able to recognize it, or at least to orientate it to a better view point allowing recognition.

The vision system, with the support of tactile sensors, classifies each piece of clothing into different categories. The database, organizing key factors for each clothing category, can be prepared in advance during experiments and training and is continuously enriched during operation while the systems learns and improves. Depending on the properties of each category, the item is

[1] http://www.leapfrog-eu.org/ (Nov 2012)

folded following a pre-specified sequence. Another issue is the definition of typical folding sequences because the literature in this field is very limited.

The task poses significant difficulty for the vision system because clothes hang freely from the two grippers and their shapes are depended on the random choice of the hanging points. For this reason, the additional information provided by tactile sensors becomes particularly important for the decision of the robot. Tactile sensors on the gripping surfaces are used to collect data about the textile roughness by performing lateral finger movements. Applied gripping forces must be carefully chosen so that the robot can handle the cloth without damaging even delicate fabrics.

IV. Garment Characterization

A. *Target Objects*

The application is focused on the handling of clothes and of casual wear in particular. Because of the enormous diversity of clothing item in terms of shape, weight, and fabric the robot gripper is required to be highly adaptive to different pieces.

To assess the require properties of the developed system, and to evaluate its performance, it is important to correctly estimate a representative set of manipulated objects. It is therefore necessary to study the typical categories of clothing and their material properties.

Gathering typical fabrics and clothes is the first important step. These collections can be the training sets for the vision and sensing system. The popularity of each type of clothes is reflected by the quantity of their articles in online shops.[2]

TABLE I. Typical Laundry Heap

Categories	Women	Men
Top	Shirt	Shirt
	T-Shirt	T-Shirt
	Sweater	Sweater
	Cardigan	Hoodie
	Top	
	Dress	
Bottom	Jeans	Jeans
	Pants	Pants
	Skirt	

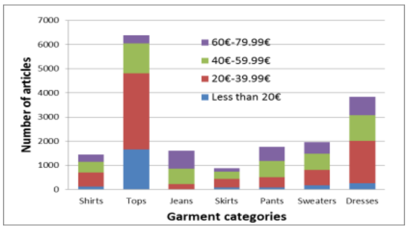

Figure 1. Garments for women

From Fig. 1 we can infer the shopping habits of people and use this information to define a typical collection one can expect in handling laundry at home. This “reference laundry heap” is presented in Table I. Although it cannot be claimed that set is a statistically representative sample of laundry items, it can be used as an initial benchmark example for the targeted application.

B. *Experiments with Grasping and Lifting Forces*

In order to achieve efficient handling without damage to the clothes, several series of experiments have been performed to define the suitable ranges of the needed applied forces. There are two types of forces: grasping force applied by the fingers, and lifting force applied by the robot arms.

Grasping force: The grasping force is related to the friction between the finger pad and the textile surface. The roughness of the clothes has strong impact on the value of the applied force. The experiments are designed with a sensor-covered glove. Subjects wear the glove and perform grasping gestures from a laundry heap. The grasping force normal to the finger pad is measured and evaluated. The tactile sensors used in the glove are capacitive and force-sensitive resistors. Their results are compared to obtain the consistent values.

Lifting force: We use the load cell of Metior[3] for evaluating the lifting force. All the pieces of clothing are first weighed and then picked from the laundry heap. The difference between these values reflects the static and dynamic loads impacting on the robot arm while the garment is picked. These results are shown in the Fig. 2. Each piece is picked 10 times from a heap of 9 garments.

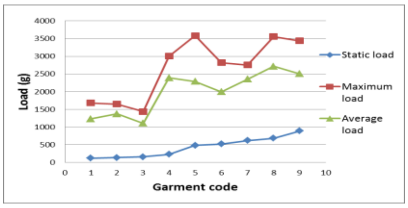

Figure 2. Variation of garment load

To illustrate how the size of the heap affects the dynamic weight of the cloth, the same garment is picked from heaps with different sizes (numbers of articles in the heap). It turns out that the dynamic weight of the garment is roughly proportional to the number of pieces of clothing in the heap (Fig. 3)

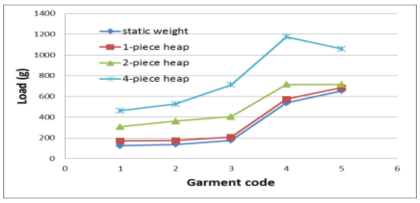

Figure 3. Load for lifting a garment from heaps of different sizes.

V. Architecture and Design of the Gripper

[2] www.amazon.fr (Mar 2012)

[3] www.metior.it (Jun 2012)

In order to complete the task, the gripper has to satisfy various requirements related to fabric handling. These can two main groups: (i) the properties of fabric or limp material and (ii) the applied force.

A. Gripper Requirements

For garment handling tasks, such as sorting, folding, and unfolding, the human hand is the basic template. The careful study of how humans handle clothes can reveal the motion capabilities that are necessary and sufficient to efficiently perform virtually all likely manipulation tasks. By limiting the motion capabilities, namely lowering the degree of freedom (dof) and the number of actuators, in a way that allows only the required movements, it is possible to significantly reduce the gripper's mechanical complexity and simplify its control while maintaining the required handling.

According to the scenario, the hard contact surface is the first issue needed to be overcome. High flexibility prevents the gripper from breaking while approaching the garment heap. The opening stroke of the gripper is designed to ensure it can pick thick garments tangled in the heap. After picking the garment, the robot has to reorient it for the recognition process. If the vision system cannot map the garment image to any category, the robot changes to another hanging point. This procedure requires the gripper tip to be small enough (comparable to a human finger) to reach the new picking point while the piece hangs freely from the other hand. When recognized, the garment is spread on the hard surface prepared for the folding process. It is difficult to lift a flattened garment if the gripper tip is too thick. Thus, the handling task requires a small and thin fingertip that can exert an adequate gripping force preventing garment from slipping.

The function of the finger is not only to pick and hold clothing but also to support the cognitive system by providing tactile sensing information. Data are collected while sliding the two gripper tips, an approximation of the human finger rubbing movement. The better the control of this movement, the more precise the acquired data is.

B. Design of the First Prototype

The first model (Fig. 4) is designed with two fingers actuated by an industrial electrical gripper. This combination is chosen to fulfill the requirements both in gripping force and opening stroke. The design includes spaces for the integration of a camera, tactile sensors, and their connection wires. The lateral movement is initially provided by a flexible bar. This bar also improves the flexibility when the lower finger touches the hard surface.

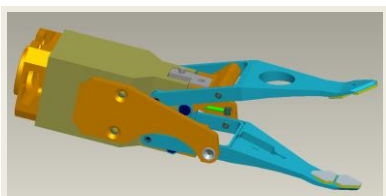

Figure 4. Model of the gripper prototype.

The whole mechanism is made in plastic (PA12) except the flexible metal bar. With this material, and the passive actuator bar, the gripper can bend without breaking while contacting the surface. The finger tips are covered with tactile sensor (Fig. 5). Maximum opening of the gripper is 82 mm and it can apply up to 25 N of gripping force. Experiments with clothing items have been confirmed that the gripper meets most of the design requirements at an acceptable level. However, more experiments and modifications are necessary to validate and enhance all the functions of the gripper.

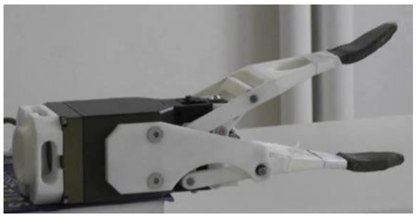

Figure 5. Gripper prototype.

VI. CONCLUSION

A robot system for automatic handling of garments needs a robotic gripper suitable for limp materials. The task imposes a number of key requirements, including an adequate grasping force, mechanical flexibility, and sufficient dexterity for tactile exploration. An adequate initial solution of the design problem has been obtained, but more work lies ahead. In particular, force transmission is being improved, the rubbing motion control will be optimized, and the adaptive flexibility of the palm is being implemented. Moreover, the performance of the tactile sensors will be enhanced by further experiments which will create a better dataset for the whole system.

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REFERENCES

[1] T. Iberall and C.L. Mackenzie, “Opposition space and human prehension,” in *Dextrous Robot Hands*, S. T. Venkataraman and T. Iberall, Eds. Springer-Verlag New York, 1990, USA, pp. 32-54.

[2] S. J. Lederman and M. M. Taylor, “Fingertip force, surface geometry and the perception of roughness by active touch,” *Perception and Psychophysics*, vol. 12, no. 5, pp. 401-408, September 1972.

[3] M. R. Cutkosky and R. D. Howe, “Human grasp choice and robotic grasp analysis,” in *Dextrous robot hands*, S. T. Venkataraman and T. Iberall, Eds. New York: Springer-Verlag, USA, 1990, pp. 5-31.

[4] R. L. Klatzky and S. Lederman, “Intelligent exploration by the human hand,” in *Dextrous robot hands*, S. T. Venkataraman and T. Iberall, Eds. New York: Springer-Verlag, USA, 1990, pp. 66-81.

[5] S. Hand. (2012). Shadow Robot Company. [Online]. Available: http://www.shadowrobot.com/hand/

[6] H. Liu, K. Wu, P. Meusel, N. Seitz, G. Hirzinger, M. H. Jin, Y. W. Liu, S. W. Fan, T. Lan, and Z. P. Chen. “Multisensory five-finger dexterous hand: The DLR/HIT Hand II,” in *Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems*, Nice, France, 22-26 September 2008, pp. 3692-3697.

[7] R. O. Ambrose, H. Aldridge, R. S. Askew, R. R. Burridge, W. Bluethmann, M. Diftler, C. Lovchik, D. Magruder, and F. Rehnmark, "Robonaut: NASA's space humanoid," *IEEE Intelligent Systems and their Applications*, vol. 15, no.4, pp. 57-63. July/August 2000.

[8] K. Emantaev, "Design of an underactuated robotic hand with grasping and emotional gestures expression abilities," Master's thesis, Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, 2011.

[9] G. Schulz, "Grippers for flexible textiles," in *Proc. Fifth Robots in Unstructured Environments*, Pisa, Italy, 19-22 June 1991, vol. 1, pp. 759-764.

[10] P. M. Taylor, A. J. Wilkinson, G. E. Taylor, M. B. Gunner, and G. S. Palmer, "Automated fabric handling problems and techniques," in *Proc IEEE Int. Conf. on Systems Engineering*, Pittsburgh, 9-11 August 1990, pp. 367-370.

[11] E. Ono, K. Kitagaki, and M. Kakikura, "Picking up a piece of fabric from layers by a hand with 3 fingers and a palm," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, Maui, Hawaii, 29 October-3 November, vol. 2, pp. 931-936.

[12] Z. Doulgeri and N. Fahantidis, "Picking up flexible pieces out of a bundle," *IEEE Robotics & Automation Magazine*, vol. 9, no. 2, pp. 9-19, June 2002.

[13] J. Maitin-Shepard, M. Cusumano-Towner, J. Lei, and P. Abbeel, "Cloth grasp point detection based on multiple-view geometric cues with application to robotic towel folding," in *Proc. International Conference on Robotics and Automation*, Anchorage, Alaska, May 3-8. 2010.

[14] Robotiq. (2012). [Online]. Available: http://robotiq.com/en/

[15] R. G. Radwin, S. Oh, T. R. Jensen, and J. G. Webster, "External finger forces in submaximal five-finger static pinch apprehension," *Ergonomics*, vol. 35, no. 3, pp. 275-288, March 1992.

[16] M. C. Ferrari de Castro and A. Cliquet Jr., "An artificial grasping evaluation system for the paralyzed hand," *Medical & Biological Engineering & Computing*, vol. 38, no. 3, pp.275-280, May 2000.

[17] A. Kargov, C. Pylatiuk, J. Martin, S. Schulz, and L. Döderlein, "A comparison of the grip force distribution in natural hands and in prosthetic hands," *Disability and Rehabilitation*, vol. 26, no. 12, pp. 705-711, June 2004.