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Assembly Strategy for Deformable Ring-Shaped Objects

Yitaek Kim[1] and Christoffer Sloth[†]

Abstract— **This paper presents a method for assembly of deformable belts onto pulleys using two robots. The idea is to let the robots work in a master-slave relation where the master robot performs a desired motion of the belt, while the slave robot tightens the belt to ensure certainty in the configuration of the belt.**

The method is demonstrated for the assembly of a rubber belt onto two pulleys.

I. INTRODUCTION

Grasping and manipulation of deformable objects have challenged robotics researchers for many years, since deformable objects complicate the manipulation task, by having dynamics that should be considered in the manipulation task. Industrial assembly tasks involving deformable objects are thus difficult to automate, since assembly tasks often require high accuracy for the manipulation of the objects. Examples of deformable and flexible objects in industrial assembly include belts, wires, and foam.

Manipulation and grasping of deformable objects can be accomplished by modeling their dynamics. However, small discrepancies between the real belt and the model can cause failure of a manipulation task. Although computer vision and machine learning methods can be used to estimate deformable objects; this always has a variety of uncertainty and adds complexity to the system.

This paper addresses the above mentioned problems, by proposing an assembly strategy for deformable ring-shaped objects utilizing two manipulators. To be specific, we focus on how to assemble a rubber belt into the groove of a pulley and verify the strategy through demonstration of the belt insertion task, which is one of the assembly tasks in the industrial robot assembly competition, WRS2020 (World Robot Submit).

A. State of the Art

The modeling of deformable objects has been addressed with various classes of models like the most widely used mass-spring model, multi-body model and other elastic models [1]. Firstly, the mass-spring model has the advantage to implement easily, but also has the drawback of the accuracy of the designed models. Likewise, the mainly exploited in robotics, the multi-body model also lacks the accuracy of the models. To achieve more accuracy, the elastic rod model with respect to the stress and the strain can be used to do modeling of cable-like models. Finally, the dynamic spine model based on the elastic rod models can reduce the size of calculation even if the model offers a higher level of geometric model's figures.

Controlling modeled flexible objects using manipulators was also conducted with computer vision and sensory feedback system [2]. In order to control deformable objects more accurately, analytical dynamic models of manipulators were utilized as well [3]. On the other hand, deformable objects were able to be assembled without the specific modeling of that one through defining the state of parts like a rubber belt and fixed pulleys [4]. In particular, this study is similar to our proposed assembly strategy.

Much research also exists on motion planning of flexible objects using dexterous manipulators. One of the motion planning methods considered ring-shaped objects was carried out with dual manipulators to optimize a path trajectory reducing energy costs [5]. Moreover, the motion planning of shaping deformable objects with external contacts was suggested as well [6]. Another controller based on computer vision was also used for deformation control of flexible objects in [7], [8].

II. METHOD

The purpose of this section is to introduce the proposed strategy for assembly of deformable belts on pulleys and provide an overview of the control system designed to complete the desired behavior.

A. Strategy

We propose a strategy for assembling a belt into multiple pulleys through controlling dual-arm manipulators. The idea is to have a master robot that manipulates the belt by completing a motion designed with motion planning, while the slave robot maintains proper tension of the belt. This strategy minimizes the uncertainty of the belt's position; thus, the motion planning algorithm models the belt as a straight line between constraints (robot fingers or pulleys). The proposed assembly sequence is shown in the following:

1) **Initialize**: Grasp the belt with the two robots, move to initial pose, and let the slave robot tighten the belt, see Fig. 1(a).
2) **Define reference point**: Find point p_{ref} on the belt that is closest to the TCP of the master robot and can be placed in the groove of the pulley without collisions.

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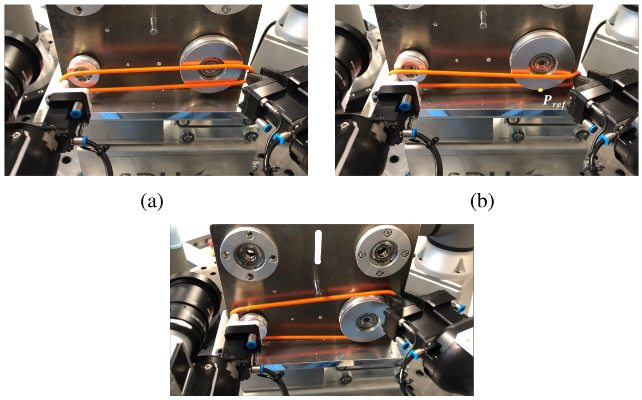
[1]Yitaek Kim is a research assistant with SDU Robotics, The Maersk Mc-Kinney Moller Institute, Syddansk Universitet, Campusvej 55, Odense M 5230, Denmark yik@mmmi.sdu.dk

[†]Christoffer Sloth is an associate professor with SDU Robotics, The Maersk Mc-Kinney Moller Institute, Syddansk Universitet, Campusvej 55, Odense M 5230, Denmark chsl@mmmi.sdu.dk



(a) (b)

(c)

Fig. 1. (a) Tighten belt at the initial position. (b) Move the desired rubber belt's point p_{ref} into the groove of the pulley using two robots. (c) Assemble the belt to the big pulley on the right hand side of the picture.

3) **Attach belt**: Let the master robot move reference point p_{ref} into the groove of the pulley, as shown in Fig. 1(b). The slave robot ensures tightness of the belt, while avoiding collisions.
4) **Assemble belt**: The master robot circumnavigates the pulley with its TCP as shown in Fig. 1(c), and releases the belt.

Note that the above procedure can be repeated if the belt should be assembled onto multiple pulleys, by repeating the procedure from 1) and possibly reassigning roles of the two robots.

B. Control System

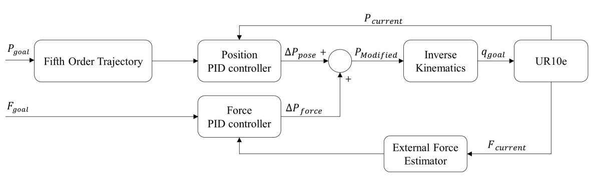
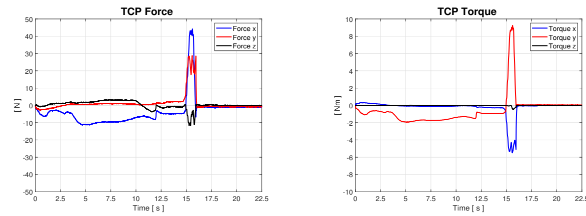


Fig. 2. Overview of the control system

The two robot manipulators are controlled with hybrid position/force controllers in a real-time control system running at 500 Hz and is shown in Fig. 2. The controllers have two inputs: P_{goal}, a fifth order position trajectory and F_{goal}, a piecewise constant force reference. Specifically, UR10e robots are used for validating the assembly strategy, controlled in joint-space using position references $q_{\mathrm{goal}} \in \mathbb{R}^6$ through the ur_rtde library[1].

III. Results

The presented results are performed on an industrial assembly defined for the industrial robot assembly competition, WRS2020 (World Robot Submit). The proposed assembly strategy was carried out several times on the belt-assembly with a high success rate. You can watch the demonstration video at the link[2]. Additionally, Fig. 3 shows data about the TCP force and torque of the master robot obtained from the belt insertion task. It maintained pre-defined forces in the step 3 from 7.5s to 14.5s. And then the robot circumnavigated the pulley from 14.5s to 16.5s. The belt's tension increased, thus force and torque peaked at that time.



(a) (b)

Fig. 3. (a) TCP Force (b) TCP Torque

IV. Conclusions

This paper presented a general strategy for assembling belts onto multiple pulleys. The idea is to use two robots: one for manipulating the belt and one for keeping a high tension on the belt. The reason for having high tension on the belt is to increase the certainty of the belt's position (it can be modeled as a straight line between constraints); this simplifies the motion planning. The method was validated by repeatedly assembling a rubber belt onto two pulleys with two UR10e robots controlled with hybrid position/force controllers.

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