Dexterous Cable Manipulation: An Initial Exploration

Sun Zhaole[1]

***Abstract*— In this workshop paper, we explore dexterous cable manipulation, which uses a dexterous hand, e.g., a multi-fingered hand, to manipulate a cable to perform different tasks. We will briefly introduce some common primitives of dexterous cable manipulation, our newly designed hand, and long-horizon manipulation. The manipulations we show in the paper are a result of replaying demonstrations. We focus on pushing the manipulability boundaries of a dexterous hand, from commonly studied rigid object manipulation towards cable manipulation. By giving real-world successful demonstrations without studying any specific algorithms, we show that the dexterous manipulability can be extended to cables. The video and the full paper are available here.**

I. Introduction

Cable manipulation is widely applicable in surgical theaters, offices, textile factories, and other industries [1], [2]. Current research in DLO manipulation largely relies on single or dual parallel pinch grippers or end-effectors attached to a fixed end-tip of the DLO [3], [4], [5], [6], [7], [8]. To get rid of task-specific customization, a more dexterous but commonly used end-effector, like a multi-fingered hand, should be considered into cable manipulation.

The example in Figure 1 shows that using a multi-fingered hand to manipulate the cable has many benefits. The hand manipulates the cable in a dexterous way by first pre-grasping the cable into a more convenient position, grasping it, hooking it with the middle-finger, and performing in-hand pulling to move the cable along the hand. If a two-fingered gripper were used instead of the hand, it would be necessary to move the whole arm to perform pre-grasp and grasping and it would also need support from the table to perform the cable sliding for releasing and re-grasping.

In this workshop paper, we mainly introduce how we explore **D**exterous **C**able **M**anipulation (DCM), from primitives (Sec II), hand design (Sec III), to long-horizon manipulation (Sec IV).

II. DCM Primitives

We introduce 8 primitives for Dexterous Cable Manipulation (DCM), where each primitive represents a reusable, atomic manipulation skill that decomposes complex cable manipulation tasks into simpler sub-steps. These primitives are designed to encapsulate key interactions between the hand and the cable (e.g., grasping, hooking, orientation control), enabling modular and generalizable control strategies for long-horizon manipulations. Below, we detail the successful goal configuration for each primitive.

[1]Sun Zhaole is with University of Edinburgh. The full author list can be found in our full paper and the website, and Zhaole is the one presenting this workshop paper. Contact: `zhaole.sun@ed.ac.uk`

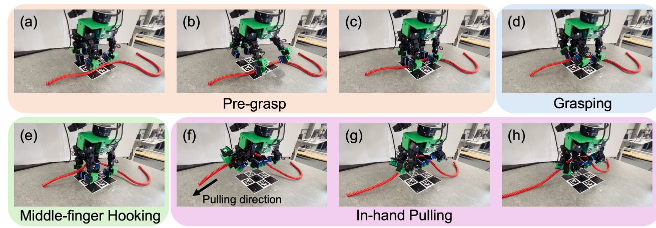

Fig. 1: Our designed hand pulling the cable from right to left. (a)-(c): The hand performs a pre-grasp motion to position the cable correctly. (d): The left-side thumb and index finger grasp the cable. (e): The middle finger bends to hook the grasped cable. (f)-(h): The left-side thumb and index finger drag the cable to the left, and the right-side thumb and index finger hold the cable to prevent it from sliding back.

1) Pre-grasp: the cable is placed between the two thumbs and two index fingers (Figure 1 a-c).

2) Precision grasp: one thumb-index combination grasps the cable and lifts it more than 3cm higher than the original height without dropping. The precision grasp is also the Z-axis position control (Figure 1 d).

3) Parallel grasp: the same goal configuration as a precision grasp, except two thumb-index combinations need to grasp and lift the cable (Figure 2 e).

4) Middle finger hooking: the middle finger hooks the grasped cable to place it between the fingertip of the middle finger and the middle metacarpal link (Figure 1 e).

For the following position and orientation control primitives, we do not set a specific angle or distance because we can always stop the hand motion early to achieve the specific goal.

5) X-axis orientation control: the cable is twisted around the X-axis by more than 22.5 degrees in both directions (Figure 2 f).

6 & 7) Z-axis orientation control: the cable is rotated around Z-axis by more than 22.5 degrees in both directions. 6) In the air means that the cable needs to be rotated while grasped in the air without dropping (Figure 2 c). 7) On the table indicates that the cable can be orientated with the support from the table without the need of being grasped, which is much easier than being rotated in the air (Figure 2 d).

8) Y-axis position control: the cable is moved in the Y-axis direction with a moving range of more than 4cm (Figure 2 d).

III. Hand Design

We use the same thumb and index fingers from the Leap Hand [9], but made several changes. Although we

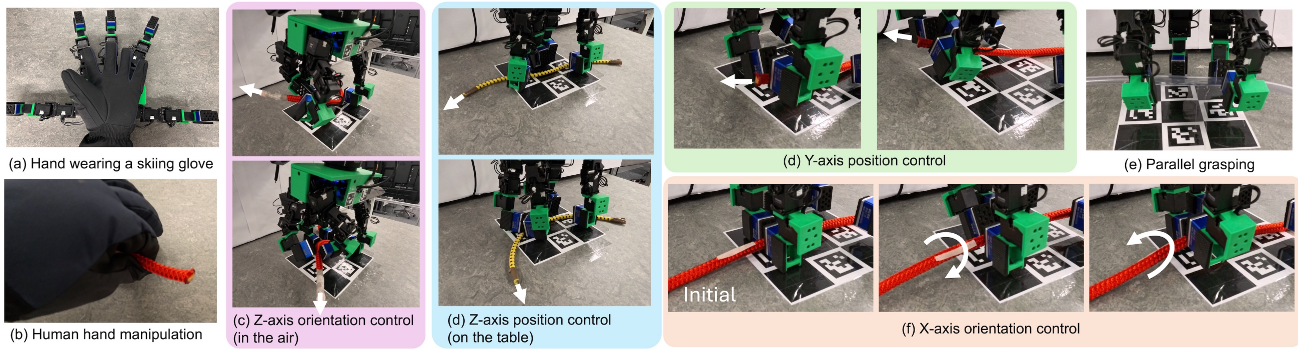

Fig. 2: (a)-(b) Human non-dominant hand wearing a skiing glove as our baseline. (c)-(f) Short-term primitives of different cables performed by our hand, where the cable's end-tip pose is highlighted with the while arrows in each figure.

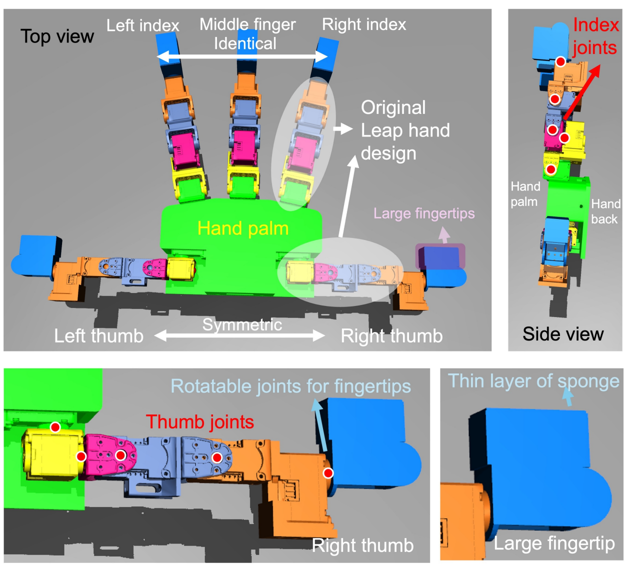

Fig. 3: A top view from the hand palm side and a side view from the right thumb side of the 2-thumbed hand rendered in MuJoCo. The red dot indicates the joint positions on each identical finger. The last blue link is the rotatable fingertip. The white areas are the finger designs from the Leap Hand. The two thumbs have symmetric structures and the other three fingers have identical structures. The hand back is mounted to the last joint of the robot arm. All fingertips are the same size with a thin layer of sponge on each.

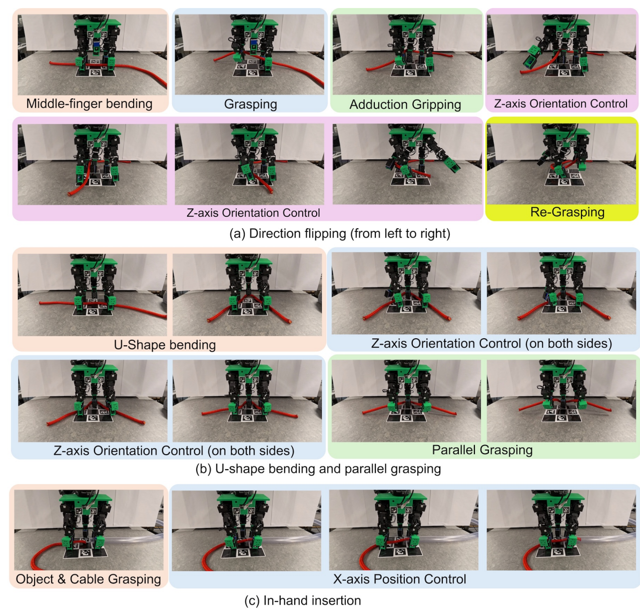

Fig. 4: Demonstrations of three long-horizon manipulations. We ignore the pre-grasp which is always the first primitive to perform. (a) Direction flipping. (b) U-shape bending and parallel grasping. (c) In-hand insertion.

still use `DYNAMIXEL XC330-M288-T` servo motors as the actuators, we used 25 motors instead of 16 motors which the Leap Hand used. Two thumbs are designed in symmetric positions considering the cable manipulation is symmetric without preference on a specific direction. Each finger has one additional rotatable fingertip to provide more dexterity on each finger, and therefore contains five actuators.

IV. Long-Horizon Manipulation

Long-horizon manipulations usually involve combinations of different primitives in order. They normally take more steps and much longer time, and are difficult to perform. Here are four long-horizon tasks of DCM:

1) Cable pulling: The cable can be pulled fully from the left to the right in the air without dropping. The cable pulling is also a form of X-axis position control (Figure 1).

2) Direction flipping: the cable's left end-tip which initially faces the left side can be turned in the air to face the right side (Figure 4 a).

3) U-shape bending and grasping: the cable can be first bent with the middle finger into a U-shape, and parallel grasped by two thumb-index combinations. The furthest part of the cable between the two thumb-index combinations is at least 5cm from the hand center in the Y-axis direction (Figure 4 b).

4) In-hand insertion: the right thumb-index combination first grasps the 2.4cm diameter hollow tube. The left thumb-index combination grasps the cable and inserts it at least 2cm into the tube (Figure 4 c).

V. Conclusion

We focus on showing several real-world demonstrations of various dexterous cable manipulation, from short-term primitives to long-horizon manipulations. Although we do not use any specific algorithm to implement dexterous cable manipulation, we show that such manipulation with a multi-fingered hand is feasible. Future studies could be a proper learning-based algorithm that can autonomously handle dexterous cable manipulation and multi-fingered hands that have very different structures compared to human hands but have similar or even better manipulation performance than human.

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