Bidirectional 1-DOF Handheld Haptic Device for Precise Differential Process Control

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***Abstract*— Existing input devices are not tailored towards providing single degree-of-freedom differential input. However, many tasks could benefit from precise bidirectional input along a single task variable, such as increasing or decreasing the level of applied force when sanding. In this paper, we present a mobile handheld haptic input device which aims to improve operator input precision via two redundant mechanically-coupled triggers. We explain the design requirements for the proposed device and describe an initial benchtop prototype used to validate the drivetrain and form factor. We conclude by discussed planned work and user evaluations.**

I. INTRODUCTION

Many tasks can benefit from precise differential control along a single process variable. For example, when drilling, an operator lowers or raises the drill position and when cutting, an operator decreases or increases the rotational tool speed. Higher-dimensional tasks can also benefit from precise one degree-of-freedom (DOF) control, for example an operator may want to independently set the applied force higher or lower when sanding. When considering prototypical applications for these types of bidirectional input, such as manufacturing settings, factors like precision, comfort, and mobility are important. Unfortunately, existing common input devices, such as joysticks or knobs, are not tailored towards these needs. In this work, we propose a mobile input device which combines two coupled triggers with a motor for creating informative haptic displays. Our main hypothesis is that the redundant two-finger operator input can improve input precision during differential control tasks. We also believe that the proposed form factor is a convenient and comfortable way to provide input using only one hand.

Existing mobile haptic inputs focus on rendering virtual surfaces rather than supplementing a precision input device. Devices in the handheld haptic space often use unidirectional inputs [1][2] or glove form factors [3][4] to convey virtual interactions. Rather than generating virtual interactions, we are interested in using haptics to supply supplemental task information, similar to haptic shared control approaches in robotics [5]. For example, we can create different stiffness profiles to convey different ranges for operator input or use virtual fixtures to guide the operator based on task models or additional sensor information.

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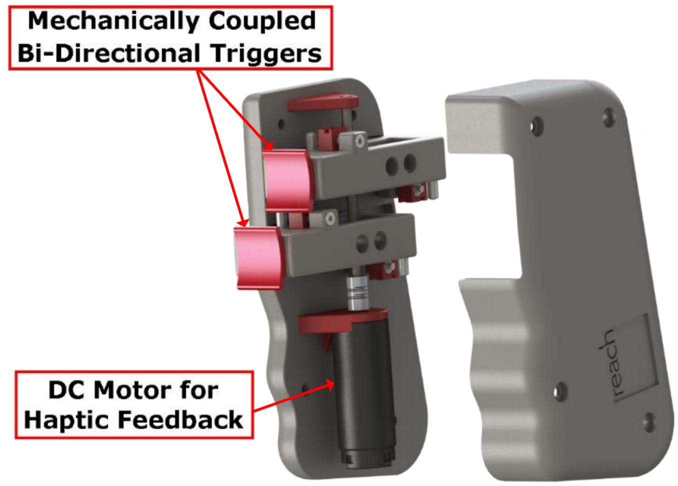

Fig. 1. Final concept design for the bidirectional haptic input. An operator provides differential input by moving the coupled triggers back and forth. A DC motor provides haptic feedback to the operator.

In this work we propose a bidirectional handheld haptic device which combines two coupled, linear triggers with a motor for generating kinesthetic haptic effects. We discuss the general device requirements followed by the design of our initial benchtop prototype. We conclude by discussing our planned future work.

II. DESIGN

The proposed design, as shown in Figure 1, is a handheld device that combines two linear triggers with haptic feedback. The two triggers are mechanically coupled via a cable transmission wound around a central shaft which is terminated at each of the triggers. The haptic feedback is provided to the user through a brushed DC motor that is rigidly coupled to the shaft. The cable transmission permits high device transparency and minimizes friction to enable quality haptic renderings.

To validate the drivetrain design, we designed and implemented a benchtop model of our proposed device as shown in Figure 2. In the following subsections, we discuss the required performance of the device and important design decisions implemented in our benchtop prototype.

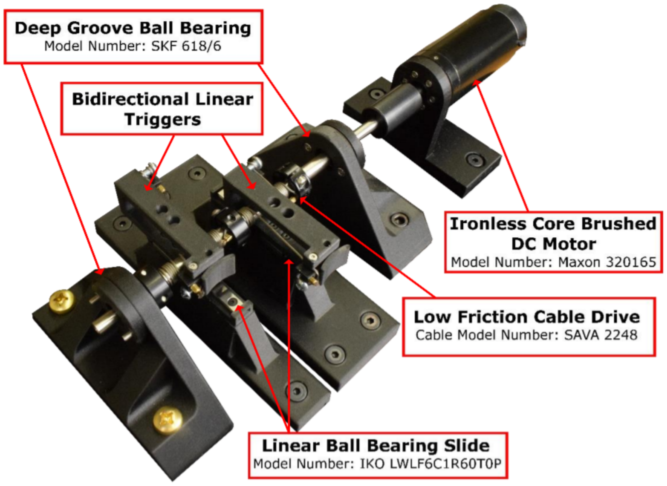

Fig. 2. Benchtop prototype for the proposed two-trigger haptic device.

A. Design Requirements

Two of the most important design criteria for the proposed device are the desired trigger reaction force (i.e., how much force should the haptic motor be able to provide) and trigger stroke length. Following the recommended contractive trigger force from Lee et al. [6], we chose a desired output force of 20 N per trigger. The choice of trigger stroke length presents a tradeoff between resolution of input and comfort. Larger strokes allow for a wider range of operator inputs, but may be more physically taxing and uncomfortable for the user. For initial testing, we chose a conservative stroke length of 30 mm, which can be trivially restricted to test shorter lengths.

B. Benchtop Design

Our benchtop prototype was designed to enable modular design configurations including modifications to trigger shapes, trigger spacing, and the trigger stroke length. The prototype leverages a cable drive reduction to transmit power from the motor to the triggers. The cable drive is a 7x49 strand stainless steel SAVA cable that is both flexible for use with a small diameter shaft and capable of a sufficiently large tension force. Based on the desired trigger output force and the cable reduction, the haptic motor is required to provide 85 mNm of torque. We use a Maxon brushed DC motor with an attached 1024 count-per-turn encoder. The motor torque is regulated with a Copley Controls Junus amplifier. Haptic effects are generated via a Speedgoat real-time controller which reads the encoder position and commands motor torque. The triggers are mounted on miniature linear bearings which are sized for the desired stroke length.

III. Future Work

With the constructed benchtop prototype, we plan to run several studies to assess the drivetrain and evaluate the precision of our input device. First, we are interested in assessing whether the drivetrain is capable of producing the desired output force. We also desire to characterize the stable range of haptic impedances that can be rendered. We plan to run a user study comparing our device to existing common inputs (e.g., joysticks, knobs) to determine whether the redundant two-finger input affords greater precision. We also plan to supplement the benchtop device with a removeable handle to test various configurations of trigger strokes, trigger geometries, and distances between triggers. We plan to use these tests to find the device configuration which maximizes operator comfort and ergonomics (e.g., reduced muscle activation measured with electromyography).

After running preliminary studies and iterating the device design based on end-user feedback, we plan to package our drivetrain into a general purpose bidirectional mobile haptic input device. In addition to testing basic device characteristics, such as precision, we will also test the mobile device in situated contexts, such as providing corrective inputs during semi-automated robot sanding [7].

We are also interested in exploring a range of haptic profiles with our device, including different stiffnesses and virtual fixtures. We are also interested in combining additional sensor inputs such as an inertial measurement unit (IMU) to increase the expressiveness of the device. For example, it might be possible to use the IMU to roughly position a robot end effector and then use the coupled triggers for precise adjustments. Finally, we are also interested in supplementing the feedback available to the user. For example, it may be desirable to supplement the kinesthetic haptic motor with a voice coil to provide operators with high frequency content.

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