Design of Robot End-Effector to Be Used in Studying Actuator-Performance for Vibrotactile Perception in a Telemanipulation Setup

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Abstract. This paper presents an overview of a work-in-progress project, where an initial case study is done to study the performance of different vibrotactile actuators. The case study was performed on six participants. Contact forces on different samples were recorded and the participants were asked to judge the change of roughness in the sample using three different actuators. A telemanipulation setup is used to increase the accuracy of recording the contact forces. Two end-effectors were designed based on measured human stiffness in x, y, and z.

Keywords: Actuator performance · Telemanipulation setup · End-effector design · UR10e

1 Introduction

Generating tactile feedback is done using vibrotactile actuators. This class of actuators is widely used in daily life devices, from mobile phones [1] to, even, in sophisticated applications such as robot-assisted surgeries [2]. There are a lot of research areas related to using vibrotactile actuators in perceiving tactile feedback. One specific research area is linked to the use of pens (stylus). The advantage of using pens in haptics, is the simplicity in design and the universal use of pens. Pen-based interface was used to validate the concept of event-based haptics in order to differentiate between real and virtual objects [3], and to create a texture model from recorded acceleration data generated from tool-surface interaction [4]. There is a gap between the performance of vibrotactile and the limit of perception. Using a telemanipulation setup would increase the accuracy of both recording and playing of the acceleration data signals, thus improving the comparison between different actuators.

2 Case Study

An initial case study was conducted on six participants Fig. 1a. The participants were presented with three different actuators, ERM-coin (ERM 1003C A),

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ERM-cylinder (KPD7C-0716) and an Exciter (EXC 221408KF A). Each actuator is mounted on a haptic pen made from aluminum. The participants were asked to hold the haptic pen in a stand still position and judge upon 16 samples per actuator, each sample consists of two different textures Fig. 1b. The judgment is based on the change of roughness at the second half of the sample compared to the first half. The contact forces were recorded using an acceleration sensor. The results of the study showed that the ERM-cylinder performed better than the other two.

One challenge faced in the case study, was maintaining the same speed and contact force while recording the signal. This challenge could be solved by using a telemanipulation setup.

(a) (b)

Fig. 1. (a): Case study to judge upon the performance of different vibrotactile actuators. (b): Texture sample. The roughness of second half is higher than the first half.

3 Telemanipulation Setup Used

The telemanipulation setup used is shown in Fig. 2. The end-effectors of both robots should be designed in a way that the ideal transparency of the recorded signal is achieved. In this case the transparency is given as follows [5]: $Z_{ss} = Z_{us}$, where Z_{ss} and Z_{us} are the total mechanical impedance on both the sensor side and the user side, respectively. Z_{ss} could be expressed as follows:

$$Z_{ss} = Z_{robot} + Z_{ees} + Z_{hp} \quad (1)$$

where Z_{robot} is the impedance of the robotic arm, Z_{ees} is the impedance of

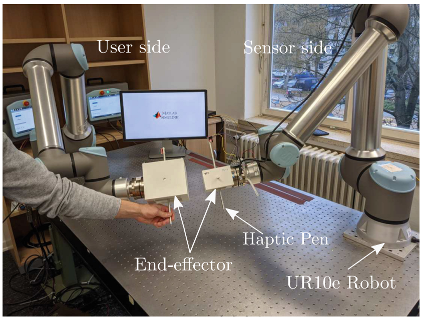

Fig. 2. Telemanipulation setup used: two UR10e robots are used, one for each side of the setup. Haptic Pen is made out of aluminum. The signal on sensor side is recorded using an acceleration sensor.

the end-effector, and Z_{hp} is the impedance of haptic pen. On the user side, in addition to the components in Eq. 1, the impedance of the user is added Eq. 2

$$Z_{us} = Z_{robot} + Z_{eeu} + Z_{hp} + Z_{user} \tag{2}$$

3.1 Measuring Human Hand Impedance

In the frequency range up to 200 Hz, the mechanical impedance of human hand is dominated by elasticity effect, especially in performing precision grasps [5]. This means that:

$$Z_{user} = c_{user} \tag{3}$$

To measure the stiffness in x, y, and z, an experiment was performed. Figure 3 shows the four contact points of a precision grasp. A linear motor moved in a sinusoidal pattern from 0 to 5 mm, and the forces acting on the human hand in each elasticity direction ($+ve\ x$, $-ve\ x$, .. etc.) were measured. The stiffness of the human hand in three axes were then calculated Table (1).

3.2 End-Effector Design

With adding Z_{user} to the user side, the end effector on the sensor side should be designed to compensate for it. Another stiffness, due to the bandwidth of the system, should be compensated. For a required bandwidth of 500 Hz and a mass of 0.04 kg for the haptic pen, $c_{bw} \approx 0.25 \frac{N}{mm}$. Helical springs with the required compensating stiffness were used. Two end-effectors were designed, one for each side of the system Fig. 2.

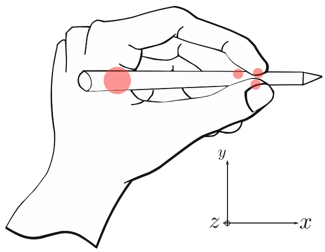

Fig. 3. Sketch of the four contact points in a precision grasp of a human hand.

4 Summary

Initial case study was made to compare between the performance of different vibrotactile actuators using pen-like tool. Telemanipulation setup would increase the accuracy of recording the contact forces. Stiffness of human hand in x, y, and z was calculated. Two end-effectors were designed. The next step would be validation of the designed end-effectors and to perform a case study to compare between the performance of different vibrotactile actuators.

Table 1. Human hand stiffness in x, y, and z

Direction	Stiffness ($\frac{N}{mm}$)
$+ve\ x$	1.26
$-ve\ x$	1.55
$+ve\ y$	0.96
$-ve\ y$	0.63
$+ve\ z$	1.35
$-ve\ z$	2.89

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