Airborne Ultrasound-Driven Passive Haptic Device Presenting Low-Frequency Vibration and Static Force

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I. Introduction

A lightweight-simple haptic device realizes haptic interaction with a low-physical burden. This study proposes an airborne ultrasound-driven passive haptic device based on a simple lever mechanism. The batteryless-lightweight device ($6.2\,\mathrm{g}$) amplifies the applied ultrasound acoustic radiation force (input force) 32.7 times by a lever and presents the amplified strong static force ($0.72\,\mathrm{N}$) to a fingerpad. Radiation force is a noncontact force produced by focusing ultrasound [1], [2]. Due to the elasticity of the fingerpad, this device also presents low-frequency vibration (2–30 Hz) with over $0.1\,\mathrm{N}$ amplitude by modulating the input force.

Amplifying radiation force by a lever is effective to develop a responsive passive actuator. As radiation force is presented at sound velocity, the amplified force is still rapidly presented, and the rapid presentation realizes a $30\,\mathrm{Hz}$ vibration presentation. Previous passive actuators (e.g. using a laser) have not covered such vibration presentation [3].

This paper provides the amplification rate and frequency characteristics of the passive haptic device. This device is partly demonstrated; however, such physical properties have not been quantitatively evaluated [4].

II. Hardware Setup

Fig. 1-A shows the fabricated device using a four-bar mechanism. By presenting radiation force (ultrasound focus) to the device tip (point of load), an amplified force is presented to the fingerpad. The focus is formed by an ultrasound phased array with 1494 transducers driven at $40\,\mathrm{kHz}$ [1], [2]. The device tip position is tracked by a depth camera (RealSense D435, Intel) at $60\,\mathrm{fps}$.

III. Physical Evaluation

A measurement setup is shown in Fig. 1-B. The passive haptic device was placed $281.9\,\mathrm{mm}$ away from the phased array. The x- and y- position was the center of the phased array and $354.2\,\mathrm{mm}$, respectively. Radiation force modulated at 2–$200\,\mathrm{Hz}$ was applied, and the amplified force was measured by the force gauge (ZTS-50N, IMADA). The force gauge tip with a $2 \times 1.5\ \mathrm{cm}^2$ acrylic plate sandwiching a gel sheet (H0-3K, EXSEAL CO., LTD.) was contacted to the point of action. The gel is used to mimic a skin-device contact. The sheet thickness, the Asker C hardness, and the Young's modulus were $3\,\mathrm{mm}$, C0, and $0.06\,\mathrm{N/mm^2}$, respectively.

The results (Fig. 1-C and D) show that the passive haptic device presents static force and low-frequency vibration (below 30 Hz). The amplification factor was 32.7. The median value of the amplified force was $0.72\,\mathrm{N}$ when the applied radiation force was constant and $0.022\,\mathrm{N}$ (maximum). The effective amplitude of the presented 2–$30\,\mathrm{Hz}$ vibration at modulation (desired) frequency was greater than $0.1\,\mathrm{N}$. In the future, we will quantitatively evaluate the perceived intensity.

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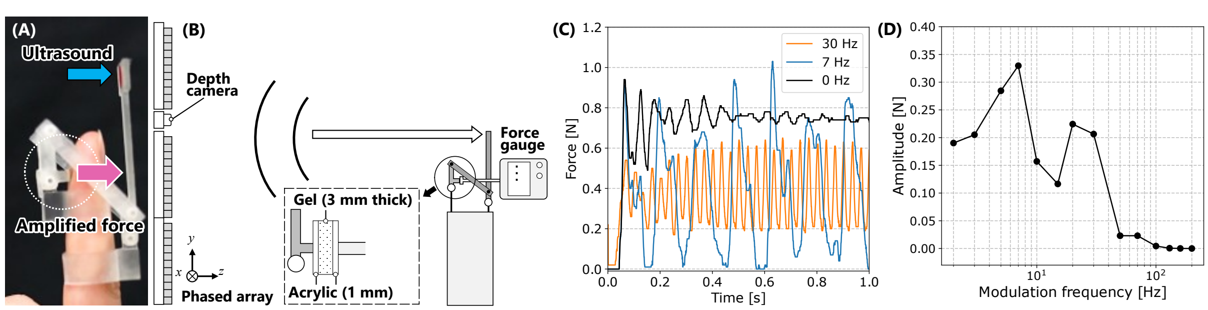

Fig. 1. A) Passive haptic device presenting 0.72 N amplified radiation force to fingerpad. B) Setup for measuring of amplified force. A force gauge tip with an urethane gel sheet contacts the stimulus part. C) Measured amplified force. D) Amplitude spectrum at modulated frequency of the amplified force.