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Vibrotactile stimulation based on the vibration of a balloon with amplitude-modulated ultrasound

Measuring vibration of the balloon for vibrotactile stimulation provided by modulated ultrasound

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Abstract : This paper proposes a vibrotactile stimulation method based on the vibration of a balloon with amplitude-modulated ultrasound, aiming to provide dynamic haptic feedback for mid-air battery-less objects. This method demonstrates the possibility for providing the dynamic haptic stimulation for 3D mid-air interaction. Furthermore, we investigated the effective modulation frequency through the measurement of the vibration of the balloon, discussed the interaction scenarios and outlined the future development.

Keyword : Aerial interface, aerial ultrasound

1. Introduction

Recently, with the development of extended reality technology like VR and AR, reality enhancement can be interpreted as involving interaction based on the five senses. Adding haptic to enhance the interaction sensitivity in 3D space becomes feasible. Manipulating midair objects in a noncontact way has a potential to provide the tactile sensation in a device- or battery-free manner. The interaction modalities explored for mid-air tangible interaction by using magnetic levitation technology [1]. It provides a vision for manipulating and interacting the object in 3D space. Different modalities also been pointed out for levitation, a new kind of robotic framework was demonstrated using a lightweight object to mimic midair robot that can be manipulated in 3D working space through acoustic radiation force [2]. It uses acoustic radiation force to construct larger space.

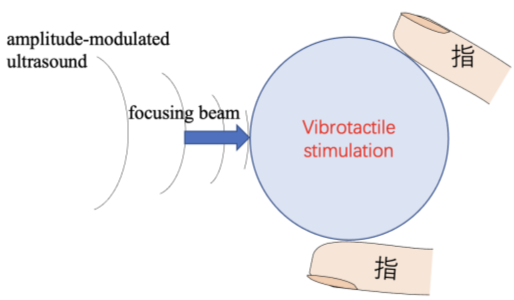

Figure 1. Proposed vibrotactile stimulation method

Also, balloon interface for midair haptic interaction [3], a system allows single-handed manipulation in 3D space. All the studies offer tactile interaction with objects in real 3D space.

Our proposal is focused on providing dynamic haptic stimulation with passive interaction acts on human hand directly through objects in real 3D space by using non-contact amplitude-modulated ultrasound. We are aiming to combine our proposed method with the airborne balloon interface which allow airborne balloon interface to present multiple types of tactile sensations.

Previous method provides single tactile sensation where our proposed method provides more possibilities. Being able to provide dynamic haptic interaction through non-contact method via light weighted object may have various applications. For instance, it can provide users with real time 3D tactile feedback like confirmation vibration feedback or target object's shaking feedback. Under the entertainment context, like shooting game or any type of team-based strategy game, once the character is vanished, our proposed method will be able to provide users a real time vibrotactile feedback to enhance the reality engagement for the game. Also, it can possibly provide various types of tactile sensations for different recipient objects.

In this paper, we proposed a method (see Figure 1) which can provide dynamic haptic feedback for objects in midair through non-contact way. During our studies, we use a light weighted balloon, and the non-contact dynamic haptic feedback was generated by focusing beam of amplitude-modulated ultrasound

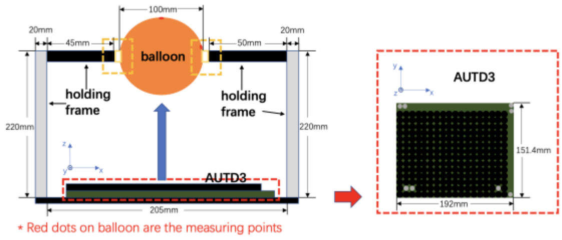

Figure 2. Experimental setup

from AUTD, provided by focusing beam emissions from one Airborne Ultrasound Tactile Display (AUTD). Same AUTD from [4] is used for our proposal. Our goal is to evaluate the effective modulation frequency acted on an object through the vibration of the object. In the following sections, we introduce how the measurement system works and the result of the measurements.

2. Experiment

2.1 Experimental setup

In order to validate the vibration of the balloon, we designed an experiment setup to imitate the situation of human hand holding balloon using 2 fingers (see Figure 2). As for the part in between the holding frame and balloon. We use the silicone rubber sheet with thickness of 0.5 cm and hardness of 10 to imitate human hand based on the similar density and elasticity (human skin of 1000kgm-3, silicone of 1030kgm-3).

Actuating AUTD for acoustic radiation force acts on balloon surface will be able to generate vibration. The focus is on the middle of the bottom of the balloon. In our proposal, we used VL-1800 Laser Doppler Vibrometer from ONOSOKKI to measure the amplitude of the vibration.

Two positions on the balloon have been measured for vibration, in order to validate the vibration on the whole surface. One is on the opposite side of the point where acoustic radiation force is applied (see Figure 4). Another measurement point is by the side of holding area (see Figure 5). Since the balloon is not transparent, we applied size of a 2mmx2mm retroreflective sheet on the surface of the balloon (see Figure 3) to ensure the LDV can get enough intensity of the reflected light.

Our proposed experiment setup contains 1 AUTD, the holding frame for balloon and one LDV for measurement.

2.2 Procedure

The LDV was hanged on the stepping motor driven stage, which is fixed on the top of the experiment bench. In the experiment, the modulated ultrasonic force was generated by AUTD, the example frequencies are taken as: 50Hz, 100Hz, 150Hz, 200Hz, 250Hz, 300Hz, 350Hz, 400Hz. For each example frequency, while the modulated ultrasonic force acting on the balloon, we used LDV to track the data for 0.1s, 0.2s and 0.4s separately. The corresponding sampling rate is 10kHz, 5kHz, 2.5kHz. The total amount of data for the data set is 1024. We performed the

Figure 3. Balloon with 2mm square retroreflective sheet

experiment twice with AUTD placed horizontally (see Figure 4) and vertically (see Figure 5), and applied Fourier transforms to the result dataset. The amplitude feature can be obtained, in this case we will be able to analyze the output amplitude with its corresponding frequency.

While the AUTD was generating the ultrasound towards the balloon, we activated the LDV to collect the data for vibration. Comprising the velocity change among different amplitude-modulated frequency. To plot the result after applying Discrete Fourier transform to the data set. From the plot, the amplitude property can be evaluated corresponding to different frequencies.

2.3 Results

While placing the AUTD horizontally, and the measurement point is located on the top of the balloon (see Figure 4). The measurement results show in Figure 6. The vibration has a maximum value while the modulated frequency acts on balloon is 150Hz. Once the frequency is over 200Hz, the vibration decreases rapidly.

We placed AUTD vertically like Figure 5 and followed the same experimental procedure as previous experiment. The result obtained for this experiment shows in Figure 7.

The overall trend for both results indicats frequency range from 50Hz to 150Hz is the best range interval to generate the vibration. While the frequency applied is 150Hz, the balloon has the largest displacement for vibrotactile performance. On the other hand, frequencies larger than 200Hz can barely generate the vibration.

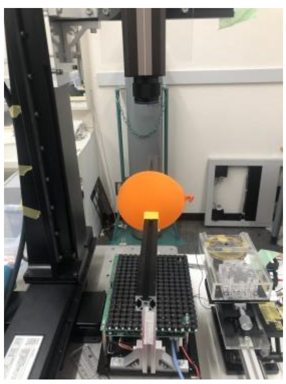

Figure 4. Horizontally

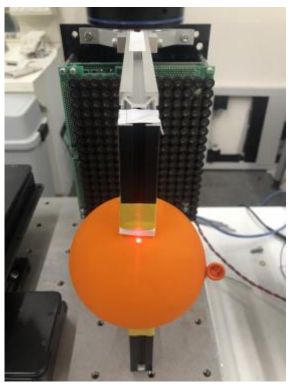

Figure 5. Vertically

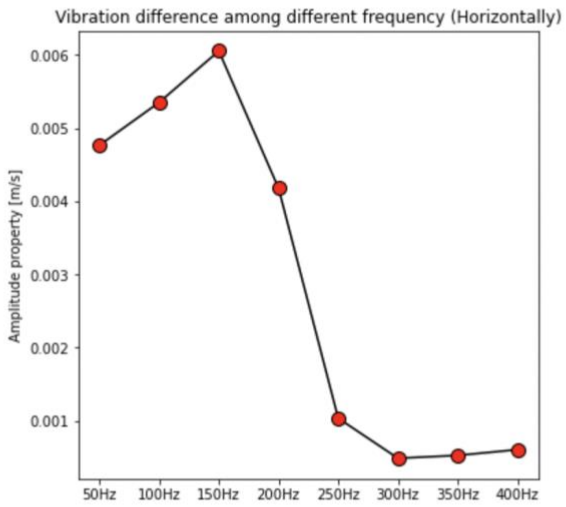

Figure 6. Vibration velocity result with AUTD placed horizontally

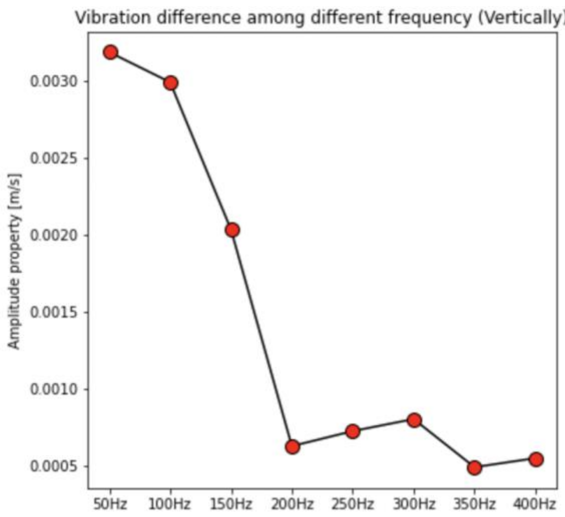

Figure 7. Vibration velocity result with AUTD placed vertically

3. Conclusion and Discussion

In this paper, we proposed a method to generate the dynamic vibrotactile stimulation for human hand via light weighted balloon by using acoustic radiation force. Considering the intensity of tactile sensation depends not only on the magnitude of the displacement, but also on the sensitivity characteristics of human skin [5]. Based on the experimental result compare with the displacement threshold of vibrotactile sensations, the proposed method generates vibrations of sufficient amplitude to provide vibrotactile stimulation at frequencies of 100Hz and 150 Hz. The data set we acquired can be used to design the vibration intensity and estimate the number of AUTD required to present vibrotactile sensation.

The proposed method has no constraint in space, recipient object can locate any position in a 3D environment. In the future, the object as the recipient is not limited to balloon only, other objects with different shapes and materials can also be used. In the future work, it can be used for providing 3D tactile feedback for any virtual input device where the aerial interface system is used as input in VR/AR environment Even though the current applications still face a lot of challenges, we will continue providing vibrotactile stimulation for different objects as our future study.

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