2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

LaserHaptics: Mid-Air Haptic Feedback via Laser-Induced Cavitation using Low Boiling-Point Liquid

Michikuni Eguchi[1], Ryota Sakuma[3], and Takefumi Hiraki[1,2]

I. INTRODUCTION

Mid-air haptic feedback, which enables non-contact tactile stimulation, has emerged as a promising technology for enhancing virtual reality (VR) experiences. By allowing the stimulation point to be freely positioned in three-dimensional space, this technology can effectively convey spatially varying tactile sensations, such as the texture of virtual objects, through dynamic mid-air stimulation.

Various energy sources have been investigated for mid-air haptics, including compressed air [1], ultrasound [2], and laser [3], [4]. Laser-based methods, owing to the excellent spatial propagation characteristics of lasers, can deliver tactile stimuli over larger areas and with higher spatial resolution than other modalities. However, safely achieving sufficiently intense stimuli remains challenging due to the low efficiency of converting laser energy into mechanical force. Because most energy is dissipated as heat rather than producing perceivable forces, high-energy laser pulses are required, posing a risk of skin damage. To comply with safety standards, emitted energy must be strictly limited, often preventing the generation of adequate tactile sensations.

To overcome these limitations, we propose a mid-air haptic feedback method using laser-induced cavitation (Fig. 1). When a high-energy laser pulse is focused into a liquid, it creates a cavitation bubble whose collapse generates a shock wave. This produces stronger haptic stimuli than conventional laser-based methods. We employ a low-boiling-point liquid to enhance cavitation efficiency and encapsulate it in a flexible pouch that adheres to the user's skin, transmitting the shock waves as tactile stimuli. In this paper, we evaluate the proposed haptic feedback method by measuring pressure waves and temperature changes during laser irradiation. We also compare its stimulation intensity with conventional laser-based haptic feedback methods [3].

II. METHOD

Laser-induced cavitation [5] is a phenomenon where a focused laser pulse generates a vapor bubble in a liquid, which rapidly collapses to produce a shock wave. The process begins with localized heating at the focal point, causing the liquid to boil and form a low-pressure bubble. The surrounding liquid pressure then causes the bubble to collapse, generating a shock wave with peak pressures reaching 10-100 MPa [5], equivalent to 100-1000 times atmospheric pressure.

*This research supported by JSPS KAKENHI Grant Numbers JP23K16918, JP23H04328, JP25K00145, and JP25H00722, and JSPS Fellows 25KJ0652

[1]M. Eguchi and T. Hiraki are with University of Tsukuba, Ibaraki, 305-8550 Japan. e-mail: {eguchi, hiraki}@mvml.slis.tsukuba.ac.jp

[2]T. Hiraki is with Metaverse Lab, Cluster, Inc., Tokyo, 141-0031 Japan.

[3]R. Sakuma is with the University of Tokyo, Tokyo, 113-8656 Japan. e-mail: sakuma@akg.t.u-tokyo.ac.jp

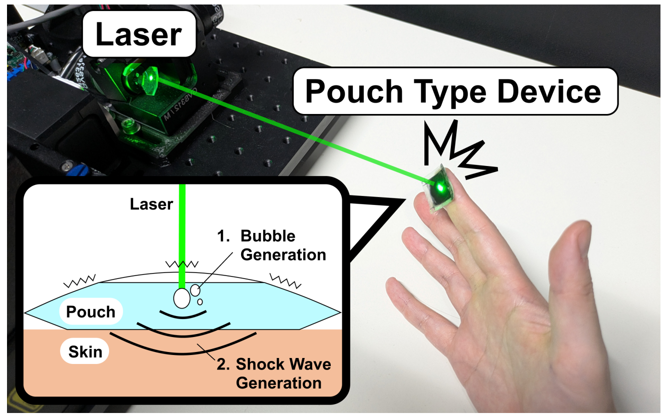

Fig. 1: Conceptual image of our proposed haptic stimulation mechanism: laser irradiation of the liquid within the pouch induces bubble formation, which subsequently generates shock waves that are transmitted to the human skin.

To utilize laser-induced cavitation for haptic feedback, we constructed a pouch-type device as shown in Fig. 1. The pouch's structure is created by heat-sealing two plastic films (Nylon Poly B type, Fukusuke Industries). Users can attach this device to their skin using double-sided tape and receive haptic stimuli when the laser is irradiated onto it.

Inside the pouch, we encapsulated hydrofluoroether (Novec 7000, 3M Company) as the working liquid. This liquid has a boiling point of 34 °C, which is lower than that of water, enabling efficient conversion of laser energy into bubbles. To enhance laser light absorption, the liquid is dyed with black pigment (NUBIAN BLACK TH-807, Orient Chemical Industries).

III. EXPERIMENTS

We conducted two experiments to evaluate the proposed haptic feedback method under laser irradiation:

1) **Pressure and temperature measurements under varying laser energy**
2) **Comparison of pressure and temperature across different materials**

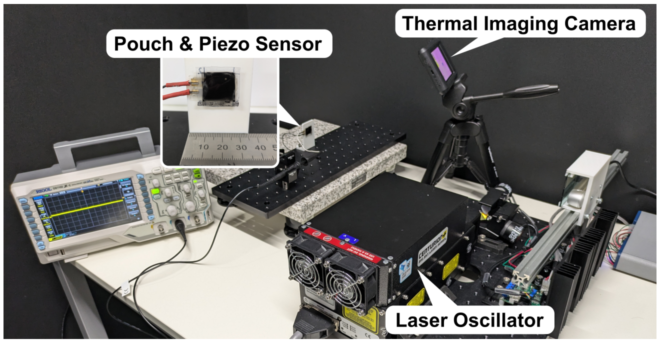

Fig. 2: Experiment environment

A. Setup

Fig. 2 shows the experimental setup. We used a short-pulse laser oscillator (Centurion+, Lumibird) with a wavelength of 1064 nm, a pulse width of 13.4 ns, and a spot size of 3.89 mm. The pouch was mounted on an anti-vibration table (VPG2836, Nabeya). The laser was directed to a 15×15 mm pouch located 400 mm away from the laser using a galvo scanner (GVS-312M, Thorlabs). For pressure measurement, we used a piezoelectric film sensor (LDT0-028, TE Connectivity) with a range of 1.08 kPa to 10.8 MPa, monitored by an oscilloscope (MSO5074, RIGOL). We measured temperature using a thermal imaging camera (HIKMICRO Pocket2) with 0.04 °C resolution at 5 Hz.

B. Laser Energy Variation

We measured the pouch's pressure waves and temperature under varying laser pulse energies (1-10 mJ, 1 mJ steps) at 10 Hz for 30 seconds. The initial pouch temperature was 27.4-27.6 °C.

Fig. 3 shows the pressure waveform synchronized with laser pulses. The waveform transitions over approximately 100 μs, indicating rapid pressure changes in the pouch. Fig. 4 shows that both pressure and temperature increase monotonically with laser energy. At 1-3 mJ, only a temperature rise was observed without vibration, suggesting the energy was insufficient to trigger the phase transition from liquid to gas. Linear regression analysis of pressure vs. energy (4-10 mJ) revealed a strong linear correlation, as shown in Fig. 4a, indicating that pressure output can be precisely controlled by laser energy input.

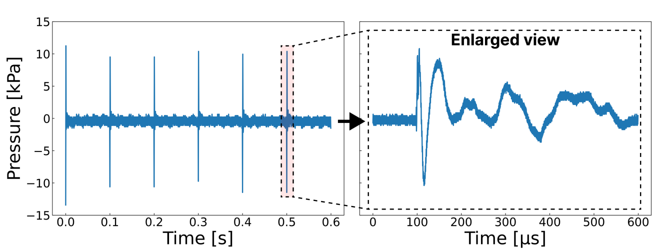

Fig. 3: Pressure waveform of the pouch (10 mJ)

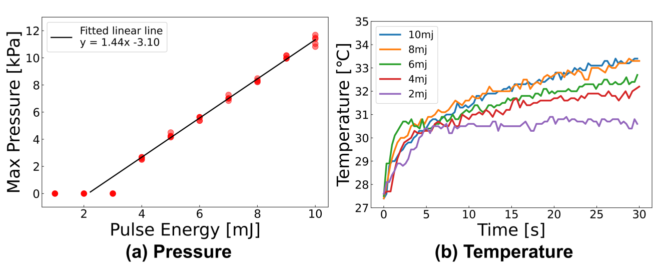

Fig. 4: Characteristics at each laser energy

TABLE I: Major properties of liquids

Material	Novec 7000	Noah 7100	Water
Boiling point (°C)	34	59	100
Density (kg/m^3)	1406	1510	997
Viscosity (mPa·S)	0.47	0.58	0.89

TABLE II: Measurement results of max pressure and max temperature at each material

	Pressure (kPa)	Temperature (°C)
Novec 7000 (Ours)	**12.6**	**33.2**
Noah 7100	6.8	36.1
Water	0.0	43.4
PVC tape [3]	7.7	60.6

C. Material Variation

We evaluated the developed pouch device by comparing pressure and heat generation across different materials. We tested three liquids with varying boiling points (Table I) and PVC tape [3] as a baseline. All materials were black-colored 15 × 15 mm squares, tested at 10 mJ and 10 Hz laser conditions for 30 seconds.

Table II shows the maximum pressure and temperature for each material. The pouch containing Novec7000 exhibited the strongest vibration (12.6 kPa) and lowest temperature (33.2°C), demonstrating superior energy conversion efficiency. Among pouch-type devices, lower boiling point liquids showed better performance, suggesting a strong correlation between cavitation and liquid phase transition. Compared to the tape-based device [3], the pouch device showed lower heat generation, as the cavitation phenomenon suppresses excessive heat through phase transition.

IV. CONCLUSION

In this paper, we proposed a mid-air haptic feedback method utilizing laser-induced cavitation. Experimental results demonstrated its effectiveness across different laser energy levels. Future work will focus on perceptual studies.

REFERENCES

[1] C. Shultz *et al.*, "LRAir: Non-contact haptics using synthetic jets," in *2022 IEEE Haptics Symposium (HAPTICS)*, 2022, pp. 1–6.
[2] T. Hoshi *et al.*, "Noncontact tactile display based on radiation pressure of airborne ultrasound," *IEEE Transactions on Haptics*, vol. 3, no. 3, pp. 155–165, Feb. 2010.
[3] H. Lee *et al.*, "Mid-air tactile stimulation using indirect laser radiation," *IEEE Transactions on Haptics*, vol. 9, no. 4, pp. 574–585, 2016.
[4] Y. Ochiai *et al.*, "Fairy lights in femtoseconds: Aerial and volumetric graphics rendered by focused femtosecond laser combined with computational holographic fields," *ACM Trans. Graph.*, vol. 35, no. 2, pp. 1–14, Feb. 2016.
[5] A. Vogel *et al.*, "Acoustic transient generation by laser-produced cavitation bubbles near solid boundaries," *J. Acoust. Soc. Am.*, vol. 84, no. 2, pp. 719–731, Aug. 1988.