Aerial Interaction with Femtosecond Laser Induced Plasma

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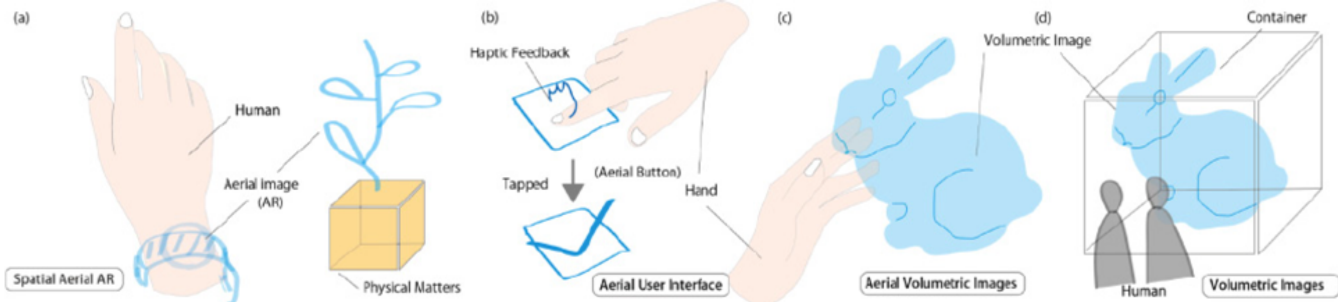

Figure 1: *These figures show the example applications of proposed laser-based graphics technology. (a) Images superposed on a hand and a box. (b) Floating button with haptic feedback. (c and d) Volumetric images rendered in open and closed areas.*

Abstract

In this article we report case studies on the aerial interaction with laser induced plasma as computational voxels. Laser induced plasma of air can be utilized to generate light source or tactile components for aerial interactions. In current studies we transformed ordinary air into interactive visual media [Ochiai et al. 2016b] and haptic media [Ochiai et al. 2016a]. To implement these interactive media, we employed Computer Generated Hologram and rendered with laser induced plasma generated by femtosecond laser sources with Spatial Light Modulators and ultrasound generated by acoustic phased array. In article, we introduce the concept through these studies and results of our research group in aerial touch display project called Fairy Lights in Femtoseconds [Ochiai et al. 2016b].

Keywords: Aerial Display, Haptic Display, Augmented Reality.

Concepts: •**Hardware** → **Emerging optical and photonic technologies;**

1 Plasma Light Source

We envision a laser-induced plasma technology in general applications for public use. If laser-induced plasma aerial images were made available, many useful applications such as spatial aerial AR, aerial user interfaces, volumetric images could be produced. This technology could be used not only for aerial images, but also volumetric displays in certain media, *e.g*. in a water-filled pool. This would be a highly effective display for the expression of three dimensionalinformation. Volumetric expression has considerable merit because the content scale corresponds to the human body; therefore, this technology could be usefully applied to wearable materials or spatial user interactions. Further, laser focusing technology can add an additional dimension to conventional projection technology, which is designed for surface mapping, while laser focusing technology is capable of volumetric mapping. This technology can be effectively used in real-world-oriented user interfaces. High-power lasers are used to generate voxels in the air. The basic concept was discussed and the working principle was demonstrated using a nanosecond laser in [Kimura et al. 2006] and a rendering speed of 100 dot/sec was achieved. In [Ochiai et al. 2016a; Ochiai et al. 2016b], we achieved high resolution and interactive application with Spatial Light Modulators and Femtosecond laser source.

The design space and possible scenarios of the plasma-based 3D display are shown in Figure 1. Adding to femtosecond laser sorce, we use an optical device, called the spatial light modulator (SLM), to modify the phases of light rays and produce various spatial distributions of light based on interference. A liquid crystal SLM (LC-SLM) is used in this study, which contains a nematic liquid crystal layer. The molecule directions within this layer are controlled by electrodes, *i.e*. pixels, and the phases of light rays reflected by this layer are spatially modulated according to the directions of the liquid crystal molecules. In other words, this device acts as an optical phased array. Figure 2 shows example images rendered in air by a femtosecond laser. While the instantaneous energy is sufficiently high to induce a plasma in air, the time-average energy of a femtosecond laser is relatively low energy that one can touch the plasma images with a finger.

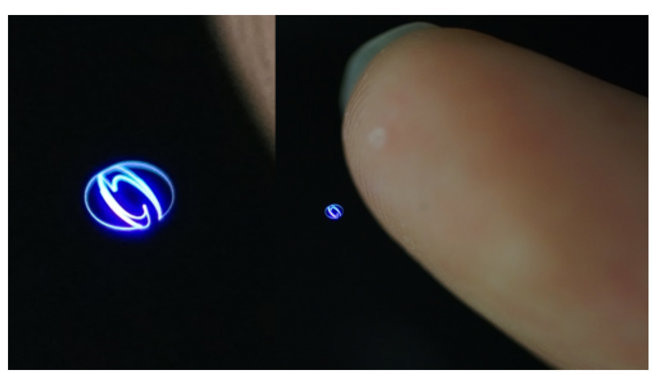

Figure 2: *Images rendered by femtosecond plasma.*

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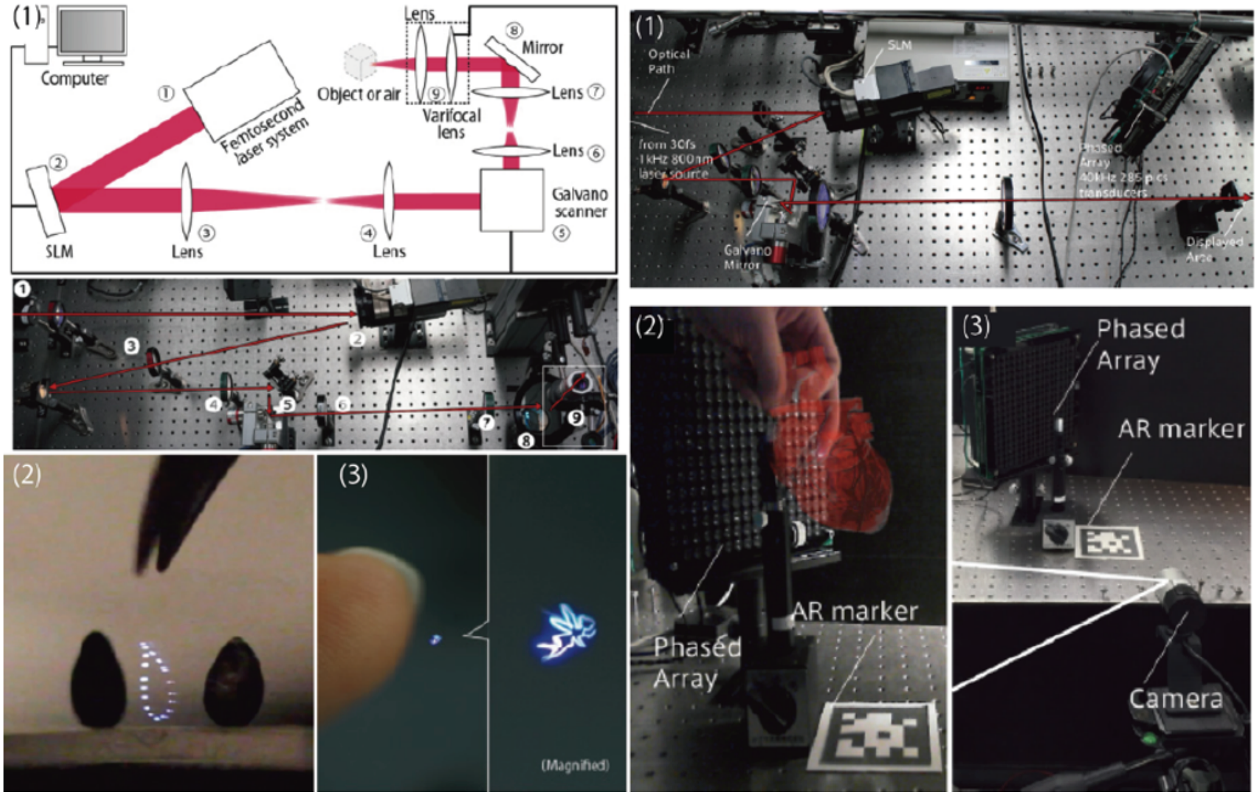

Figure 3: *System and Applications: Left(1-3) Fairy Lights in Femtoseconds [Ochiai et al. 2016b], Right (1-3) Cross-Field Haptics [Ochiai et al. 2016a]*

2 Case Studies: Visio Haptic Media

Here we introduce the project named Fairy Lights in Femtoseconds [Ochiai et al. 2016b] and additinal haptic project called Cross-Field Aerial Haptics [Ochiai et al. 2016a].

Systems are shown in Figure 3 (1)-left and (1)-right. We have utilized femtoseconds laser source and spatial light modulator to generate laser induced plasma by laser light fields in three dimensionally positions.

[Ochiai et al. 2016b] is a display method of rendering aerial and volumetric graphics using femtosecond lasers. A high-intensity laser excites physical matter to emit light at an arbitrary three-dimensional position. There are two methods of rendering graphics with a femtosecond laser in air: producing holograms using spatial light modulation technology and scanning of a laser beam by a galvano mirror. The display workspace of the system proposed here occupy a volume of up to 1 cm^3; however, this size is scalable depending on the optical devices and their setup. We tested two laser sources: an adjustable (30-100 fs) laser that projects up to 1,000 pulses/s at an energy of up to 7 mJ/pulse and a 269 fs laser that projects up to 200,000 pulses/s at an energy of up to 50 J/pulse. We confirmed that the spatiotemporal resolution of volumetric displays implemented using these laser sources is 4,000 and 200,000 dots/s, respectively (Figure 2(left)). The spatial resolution of voxels is 100 m interval and participants in this study states that displayed object cannot be distinguished from physical solid materials.

[Ochiai et al. 2016a] is haptic display project combined with acoustic holograms. In this project we presented a new method of rendering aerial haptic images that uses femtosecond-laser light fields and ultrasonic acoustic fields. While these fields have no direct interference, combining them provides benefits such as multi-resolution haptic images and a synergistic effect on haptic perception. We conducted user studies with laser haptics and ultrasonic haptics separately and tested their superposition. The results showed that the acoustic field affects the tactile perception of the laser haptics. We explored augmented reality/virtual reality (AR/VR) applications (Figure 2 (Right-2,3)) such as providing haptic feedback of the combination of these two methods. Our results show that the acoustic field affects tactile perception of the laser haptics. The findings are as follows; laser tactile sensation is repressed in an acoustic field; some users can differentiate spatial patterns rendered with laser plasma; users can detect the 3D position of the laser stimulation better than the ultrasonic stimulation.

References

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