Luciola: A Light-Emitting Particle Moving in Mid-Air Based On Ultrasonic Levitation and Wireless Powering

Hao Qiu
The University of Tokyo
hqiu@iis.u-tokyo.ac.jp

Yuki Uno
The University of Tokyo
uno@iis.u-tokyo.ac.jp

Toru Sai
The University of Tokyo
sai@iis.u-tokyo.ac.jp

Shunta Iguchi
The University of Tokyo
shiguchi@iis.u-tokyo.ac.jp

Yota Mizutani
The University of Tokyo
y.mizutani@akg.t.u-tokyo.ac.jp

Takayuki Hoshi
The University of Tokyo
takayuki_hoshi@ipc.i.u-tokyo.ac.jp

Yoshihiro Kawahara
The University of Tokyo
kawahara@akg.t.u-tokyo.ac.jp

Yasuaki Kakehi
The University of Tokyo
ykakehi@sfc.keio.ac.jp

Makoto Takamiya
The University of Tokyo
mtaka@iis.u-tokyo.ac.jp

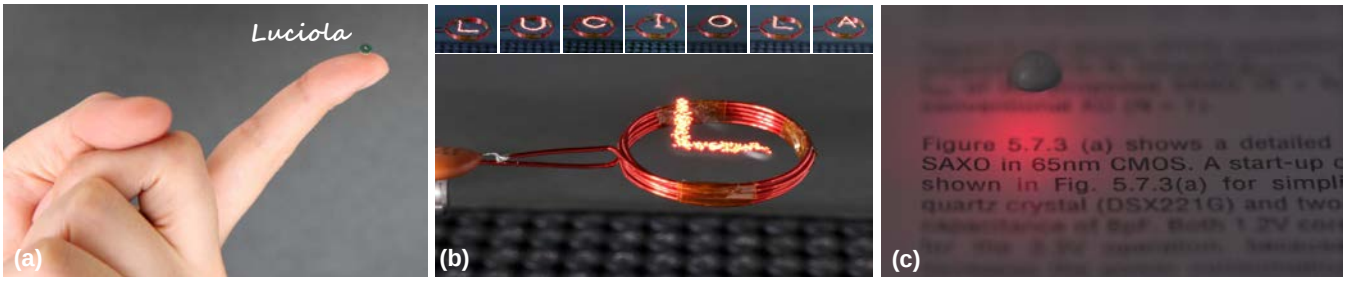

Figure 1: (a) Luciola particle on fingertip. (b) Luciola levitated by ultrasonic array and emitting light by wireless powering. (c) Luciola acting as a micro lamp in mid-air.

ABSTRACT

In this paper, we present an approach to realize the levitation of a small object with an embedded electronic circuit. Luciola is a light-emitting particle with a diameter of 3.5mm and a weight of 16.2mg moving in mid-air. The novelty of this paper is the ultrasonically levitated electronic object powered by resonant inductive coupling. To enable the levitation of a particle, a custom IC chip is essential in reducing the size and weight of the particle. Ths custom IC chip is designed to achieve an intermittent lighting of the LED, which increases the maximal distance between the transmitter and the receiver coils. Luciola is applied to a self-luminous pixel in a 3-dimensional (3D) mid-air display and the drawing of characters in mid-air is also demonstrated.

CCS CONCEPTS

• Human centered computing → Human computer interaction

SA '18 Emerging Technologies, December 04-07, 2018, Tokyo, Japan

ACM ISBN 978-1-4503-6027-2/18/12.
https://doi.org/10.1145/3275476.3275479

KEYWORDS

Millimeter-scale, ultrasonic levitation, wireless powering, IC chip

ACM Reference format:

Hao Qiu, Yuki Uno, Toru Sai, Shunta Iguchi, Yota Mizutani, Takayuki Hoshi, Yoshihiro Kawahara, Yasuaki Kakehi, and Makoto Takamiya. 2018. Luciola: A Light-Emitting Particle Moving in Mid-Air Based On Ultrasonic Levitation and Wireless Powering. In *Proceedings of SA '18 Emerging Technologies.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3275476.3275479

1 INTRODUCTION

In this paper, we propose a smart millimeter-scale particle levitated in the mid-air, which has internal electronics. In the particle scale, it has been hard to install active levitation mechanisms in the object due to their size, weight, and power consumption. Acoustic levitation is one of the most promising ways to keep the objects suspended in the air. By using ultrasonic phased array speakers, our system enables the 3D position control of levitated particles quickly and precisely. On the other hand, the particles have a strong constraint on their weight, size, and shapes to maintain its balance in mid-air. Thus, previous systems [Ochiai et al. 2016, Sahoo et al. 2016] tended to use non-electric materials, which don't have any further functions themselves, just for position controls.

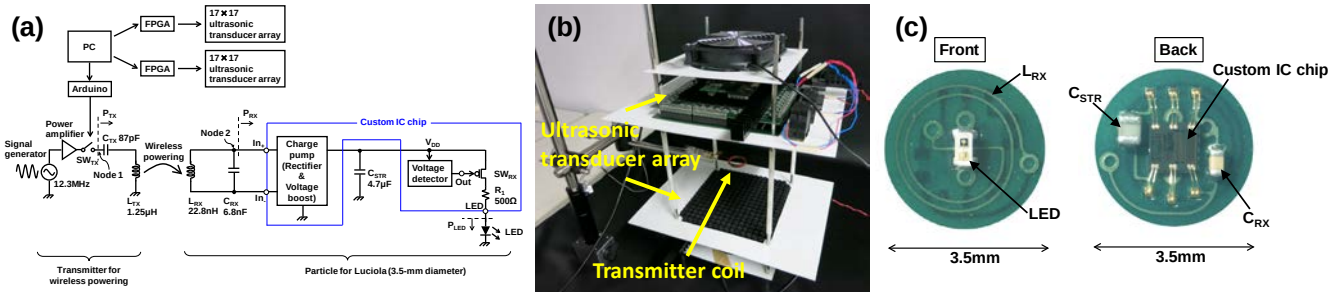

Figure 2: (a) Block diagram of Luciola system. (b) System overview. (c) Teardown photograph of particle used in Luciola.

Our ultimate goal is to make a swarm of smart levitated particles. Each tiny particle has abilities to change their appearances by sensing the surroundings and talk to each other. As a first step toward this concept, we propose Luciola [Uno et al. 2017], as shown in Figure 1(a). It is a particle consisting of the LED, the receiver coil for wireless powering, and a custom IC chip for the rectifier, the voltage regulator, and the intermittent lighting of the LED implemented in 180-nm CMOS process. Due to high integration in the custom IC chip, Luciola can satisfy the strict requirements of acoustic levitation. Its 3D position, as well as the on/off timing of the LED, can be computationally controlled, making it possible to control the lighting of the LED depending on the position and the context.

2 TECHNOLOGY INNOVATIONS

The main innovation is that we realize the acoustic levitation of an electronic object, which makes it easier to implement more functions in future applications. The key is to fabricate the levitated object as light as possible, by making it battery-less and integrated. With the embedded receiver coil, it is powered wirelessly by resonant inductive coupling. The receiver coil pattern is optimized by electromagnetic simulation to maximize its quality factor for a maximal wireless power transfer efficiency. We also designed a custom IC chip, which reduces both the area and weight by 99% compared with the conventional off-the-shelf ICs. In the custom IC chip, the charge storage circuit is utilized to achieve the intermittent lighting of the LED to increase the maximal distance between the transmitter and the receiver coils.

3 IMPLEMENTATION

Figure 2 shows an overview of the whole system, which consists of levitation and wireless powering sub-systems. In levitation sub-system, two 40kHz 17x17 ultrasonic transducer arrays are placed face-to-face with a separation of 20cm. In each ultrasonic transducer array, ultrasonic transducers (Nippon Ceramic Co., Ltd., T4010B4) and 72 drivers (IXYS Co., IX4427) are used. The ultrasound generated from each transducer is focused to a focal point, where Luciola floats, by tuning the phase of each transducer. With the new ultrasonic transducer drivers and updated driver design, we improved the stability of the original system [Uno et al. 2017] and made the levitation time increased by 5X to 10X. In wireless powering sub-system, a 12.3-MHz sine wave voltage from a signal generator (Agilent Technologies, DSO5054A) is amplified by a power amplifier (NF Corporation, HSA4101). L_{TX} (1.25μH) and C_{TX} (87pF) are the LC resonator used for resonant inductive coupling. A switch (SW_{TX}), implemented by a relay (Panasonic Electric Works, TQ2-L2-4.5V), is inserted between the power amplifier and the LC resonator. SW_{TX} and the ultrasonic arrays are controlled by a PC through Arduino Uno. By synchronously controlling the focal point of the ultrasound and the ON/OFF timing of the switch of the wireless powering, we discuss the applications of Luciola.

4 APPLICATIONS

Figure 1(a) shows a photograph of Luciola on a fingertip. Two main applications are discussed. One is drawing characters in mid-air, and the other is acting as a moving micro lamp in mid-air. Figure 1(b) shows long-exposure photographs of character drawing of “LUCIOLA” one by one in mid-air using the setup shown in Figure 2. Besides, the character drawing is not limited to two dimensions but can be extended to three dimensions, which is shown in video. Figure 1(c) shows a levitating and moving micro lamp in mid-air. In that setup, we focused the ultrasound by using one transducer array and a reflector plate. Here, the book works as the reflector plate, below which the transmitter coil is placed. Luciola is levitated above the book with the LED-side down. It moves from left to right along the line of the book and illuminates the contents in the book. In the future, its movement is expected to be automatically set with an eye-gaze tracking system.

ACKNOWLEDGMENTS

The work is supported by the Japan Science and Technology (JST) ERATO under Grant No.: JPMJER1501.

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