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# High-Clarity Underwater 3D Display Enabled by Electrolysis-Free Water-Mediated Wireless Power Transmission

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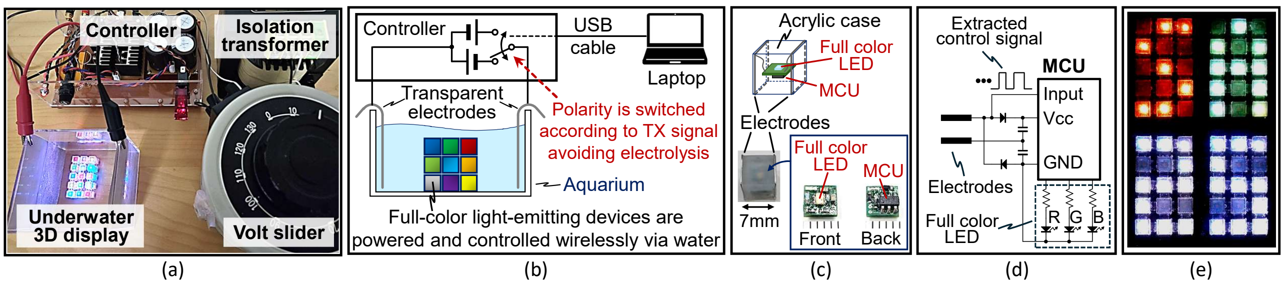


**Figure 1: Demonstration and system overview of the proposed underwater 3D display system. (a) Overall view of the prototyped full-color 3D display system. (b) System schematic and operating principle. (c) Structure of a light-emitting device. (d) Circuit diagram of a light-emitting device. (e) Example usage: the system controls device colors to display "SA25."**

## Abstract

This work proposes an underwater wireless power transfer that suppresses electrolysis while powering 7 mm cubic light-emitting devices. By reversing electrode polarity, bubble generation is avoided, preventing image degradation and enabling clear volumetric visualization. The prototyped system demonstrated stable operation with sufficient power and 115.2 kbps communication, showing the feasibility of high-clarity underwater 3D displays.

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## 1 Background and motivation

Three-dimensional (3D) displays have been investigated as next-generation visualization technologies because they provide depth perception beyond conventional two-dimensional (2D) displays [Geng 2013]. Major approaches include holographic displays, head-mounted displays (HMDs), and volumetric displays. Although holographic displays can reconstruct detailed wavefronts, they generally require large-scale optical setups and provide limited viewing angles [Zeng et al. 2017]. HMDs offer scalability and immersion, but they suffer from the vergence-accommodation conflict, which often causes visual discomfort [Kirollos and Merchant 2023]. Volumetric displays achieve natural depth perception by placing light-emitting elements in space; however, miniaturization of such devices leads to relatively bulky wiring, resulting in degraded image quality. To address this limitation, prior work demonstrated wireless powering of volumetric light-emitting devices [Qiu et al. 2018].

In our previous work [Shirai and Hashimoto 2022], we extended this concept by exploiting water as a transmission medium for wireless power and signal delivery. Fig. 2 shows the overview of our previously proposed system. This system applies high-voltage pulses with fixed polarity to transparent electrodes at both sides of an aquarium, enabling light-emitting devices to extract power and control signals directly from the surrounding water. While this approach eliminated wiring, it introduced two critical limitations. First, the unidirectional current caused continuous electrolysis, producing hydrogen and oxygen bubbles that degraded image clarity and reduced transfer efficiency, as shown in Fig. 2. Second, the method required high-voltage, high-speed switching, which constrained semiconductor-based control and limited achievable frame rates. Consequently, a practical underwater volumetric display requires a transmission method that suppresses electrolysis, ensures

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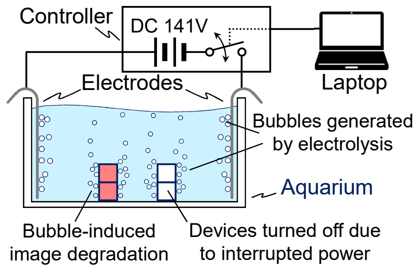


**Figure 2: Overview of the system proposed in [Shirai and Hashimoto 2022].**

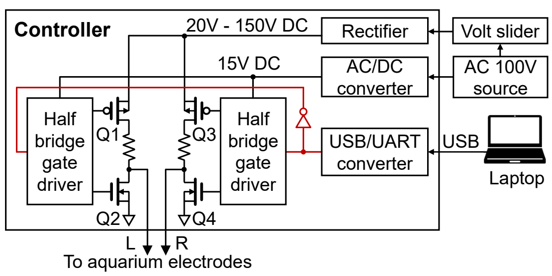


**Figure 3: Schematic of the controller.**

sufficient power for miniaturized devices, and supports high-speed communication under low-voltage operation.

## 2 Our approach: electrolysis-free underwater powering

This work proposes an underwater wireless power transfer method that suppresses electrolysis while enabling high-power delivery to miniaturized light-emitting devices, thereby improving image clarity. Fig.1(a) shows the overview of the prototyped full-color 3D display, and Fig.1(b) illustrates its operating principle. The system reverses the polarity of electrodes according to control signals, so that the electrolysis reaction, $2\,H_2O \longrightarrow 2\,H_2 + O_2$, proceeds alternately in opposite directions. As a result, hydrogen and oxygen gases are not accumulated, thereby preventing bubble-induced image degradation and enhancing power transfer efficiency.

A controller based on half-bridge drivers generates the polarity switching in synchrony with the transmitted symbols. When transmitting symbol '0', only transistors Q1 and Q4 are turned on, whereas for symbol '1', only Q2 and Q3 are turned on. This switching enables the polarity reversal of electrodes L and R according to the transmitted symbols. Unlike our previous system [Shirai and Hashimoto 2022], which applied no voltage for symbol '0', the newly proposed method continuously applies voltage to the aquarium, leading to higher transferable power. Furthermore, since electrolysis is suppressed, electrolytes can be added to enhance water conductivity, which allows efficient power transfer at relatively low voltages. This feature facilitates high-speed semiconductor switching and enables higher frame rates for volumetric displays.

Each light-emitting device incorporates a full-wave rectifier to accommodate bidirectional current, and a microcontroller (MCU) decodes the polarity to drive a full-color LED, as shown in Fig.1(d).

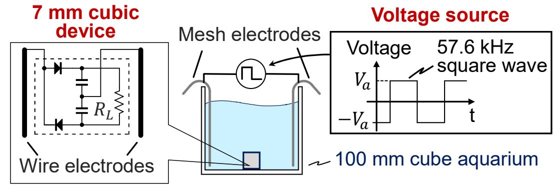


**Figure 4: Experimentation setup.**

Fig. 1 (c) shows a prototype device. Each light-emitting device is a 7 mm × 7 mm × 7 mm cube containing a 5 mm × 5 mm printed circuit board (PCB). Although using transparent electrodes would further improve image clarity, we prioritized demonstrating the proof-of-concept of a 3D display with the bubble-free wireless power transfer technique, and thus used thin copper wires wrapped around the device sides for implementation simplicity.

## 3 Evaluation

We evaluated the proposed wireless power transfer method and 3D display system with respect to the three requirements: bubble-free operation, sufficient power delivery, and high-speed communication under low voltage. Fig. 4 shows the experimental setup. A 7 mm cubic evaluation device was placed at the center of a 100 mm × 100 mm × 100 mm aquarium filled with 500 mL purified water at 25°C. The device connected a fixed load resistor ($R_L$ = 473 Ω), determined from the power consumption of the MCU and LED. The input was a square wave with amplitude of $V_a$ and frequency of 57.6 kHz, corresponding to 115.2 kbps. We varied $V_a$ and the concentration of 1 mol/L NaOH solution added to the water, and measured the received voltage.

Fig. 5 shows the results, indicating that adding NaOH reduced the required voltage amplitude to maintain 3.3 V, sufficient for stable MCU and LED operation. In the previous system [Shirai and Hashimoto 2022], 141 V switching was required to power single-color 8 mm cubic devices, limiting communication speed to 9.6 kbps. In contrast, this work achieved 115.2 kbps to full-color devices, which is 12 times faster than the previous work of 9.6 kbps, with switching voltages reduced by 29 to 64 percent from 141 V to a range between 50 and 100 V due to increased conductivity with NaOH. Notably, without the proposed polarity switching, the addition of NaOH is not feasible, as it accelerates electrolysis. This communication speed is limited only by the MCU processing rate, and faster switching is feasible using the current controller. Further speed-up will be part of our future work.

Finally, Fig. 1(a) and (e) show the prototype in operation, demonstrating stable communication and power transfer without bubble-induced image degradation. These results confirm the feasibility of bubble-free, high-speed, and high-power underwater wireless power transfer for 3D displays.

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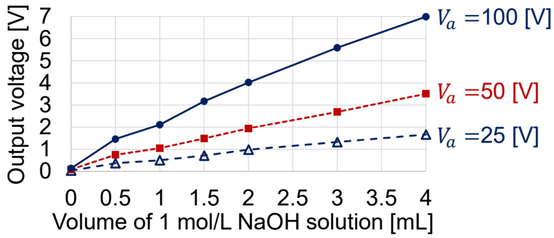


**Figure 5: Relationship between the output voltage of the test device and the volume of 1 mol/L NaOH solution added.**

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