Shape-Flexible Underwater Display System with Wirelessly Powered and Controlled Smart LEDs

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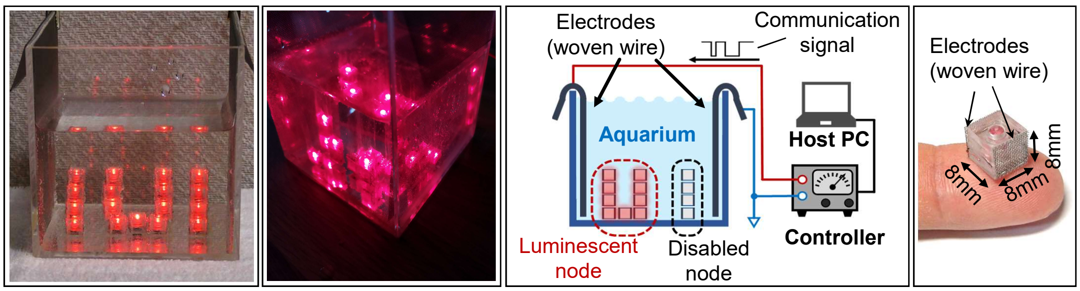

(a) (b) (c) (d)

Figure 1: Demo and overview of the proposed underwater display system. (a) Prototyped underwater display shows characters of "IUI." (b) By arranging many pixel nodes, 3D display whose structure is complex can be easily built. (c) Overview of the proposed system. (d) Photo of prototyped pixel node.

ABSTRACT

This paper proposes a 3D shape-flexible underwater display system which allows users to built a 3D display easily. To attain the flexibility, this paper proposes and evaluates the underwater wireless powering and communication method, which eliminates cables connected to each node. Simulation results show that the proposed method can deliver 4.78 mW to a 8mm × 8mm × 8mm size node and the communication speed of 9600 baud is feasible.

CCS CONCEPTS

• **Hardware** → **Displays and imagers**; **Sensors and actuators**; *Power networks.*

KEYWORDS

underwater display, wireless power transfer, scalable display

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1 INTRODUCTION

Great advances in device implementation technology has allowed us to produce novel types of display. Some of the newly developed displays, e.g., [1] and [7], change their physical device shapes and then provide more diverse ways to present information to us unlike conventional displays presenting only 2D images. On the other hand, the size of the entire display system is fixed, and hence the scalability is limited. To overcome the scalability problem, a common approach of constructing a display by aggregating many small modules is adopted in [2, 3, 10, 11]. However, in these works, the numerous wires required for connecting modules limit the scalability and furthermore degrade the vision quality seriously. To enable a truly scalable and high vision-quality display, we should eliminate the communication and power supply cables.

For eliminating power cables, magnetic field-based wireless power transfer (WPT) is a promising technology in many contexts [4, 13]. "Luciola" system [8, 12] has actualized mm^3 class luminescent particles that operate without wiring thanks to the magnetic field-based WPT. Here, the magnetic field-based WPT requires a coil to receive the energy. Most of coils are made of copper wire, and consequently the vision quality degrades when the pixel size become smaller and comparable to the coil size. A similar problem occurs in wireless communication. Most of the wireless communication circuits require coils and many electric components, which deteriorates the vision quality of the display system.

For these reasons, a coil-less wireless powering and communication method with a small number of components is highly demanded. The authors previously proposed a coil-less underwater WPT method [9]. However, communication methods suitable for the display have not been provided. Also, Ref. [9] evaluated only the relationship between the node size and the receivable power, and

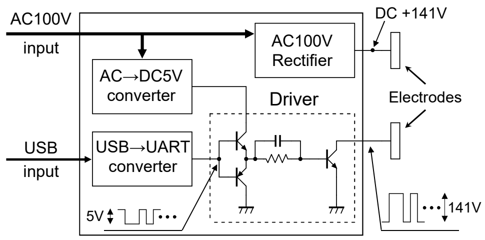

Figure 2: Schematic of the controller.

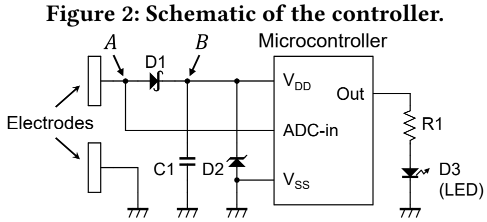

Figure 3: Schematic of the pixel node.

thus the limitation and potential of the method are still unknown. This work proposes a simple communication method compatible with [9] and reveals the features and limitations of the WPT method. This work also shows a display demo with a prototyped system.

2 PROPOSED METHOD

Fig. 1(c) shows the overview of the proposed display system. Both the controller and pixel node are equipped with two electrodes responsible for the proposed WPT and communication, where the water is used as a conducting medium.

Figs. 2 and 3 show the circuit diagrams of the controller and pixel node, respectively. The controller consists of two voltage converters, an UART signal converter, and a driver circuit. UART is one of serial communication protocols and is used for the communication between the controller and host PC. If there is no signal, the signal line of UART is kept to 5V. When the signal line is kept to 5 V, the output transistor of the driver circuit becomes on-state and the voltage between the two electrodes becomes DC 141 V, which is obtained by rectifying AC 100 V. The current generated by this DC 141 V signal flows through D1 in Fig. 3, and then powers the micro-controller unit (MCU).

When the host PC transmits data via the UART, the voltage between the two electrodes in the controller toggles between 141 and 0 V. Even in such a case, D1 and C1 retains the supply voltage for the MCU to work. The MCU always conducts A/D conversion and compares the voltage between point A (V_A) and B (V_B) in Fig. 3. If the MCU detects $V_A < V_B$ situation, MCU recognizes "receiving symbol 0." Note that too long "symbol 0" results in over-discharge of C1, and hence the communication speed must be fast to some extent. Section 3.1 evaluates this limitation. Thanks to the proposed powering and communication scheme, the pixel nodes can be freely located as shown in Fig. 1(a) and (b).

3 EVALUATION

This section conducts simulation experiments to show the feasibility and the potential of this work.

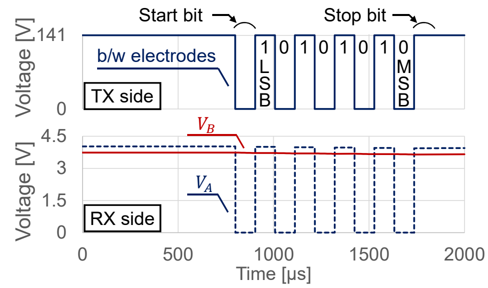

Figure 4: LTspice simulation result of the proposed underwater wireless communication method.

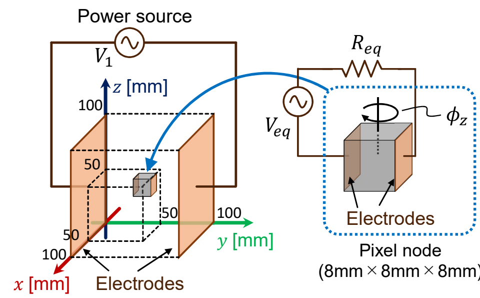

Figure 5: Simulation setup.

3.1 Underwater wireless communication

This section conducts circuit simulations with LTspice XVII to confirm the feasibility of the proposed underwater wireless communication method. As explained in Section 2, the low communication speed may bring power shortage at the pixel node. Hence, this section tests the communication speed of 9600 bps, which is common low communication speed for legacy devices. The upper figure in Fig. 4 shows the voltage between the two electrodes in the controller (TX) side and the lower figure shows the voltage at two points A and B shown in Fig. 3 in the pixel node (RX) side. Fig. 4 indicates that V_B retains around 3.9 V to keep the MCU alive even while V_A toggles according to the supplied voltage. Therefore, the MCU can sense the received symbol with ADC and hence the communication is enabled.

3.2 Underwater WPT

This section evaluates the performance of the proposed WPT method with the ANSYS HFSS electromagnetic simulator.

3.2.1 Setup. Fig. 5 shows the simulation setup and the definition of rotation angle ϕ_z. In the simulation, a pixel node whose size is 8 mm × 8 mm × 8 mm is placed at the center of the aquarium whose size is 100mm × 100mm × 100mm. By Thevenin's theorem, the equivalent circuit of the WPT system is explained with V_1, V_{eq}, and R_{eq} as shown in Fig. 5. Therefore, successive sections evaluates values of V_{eq}/V_1 and R_{eq}. As for the water conductivity σ, we used σ = 0.01 [S/m] since the conductivity of drinking water ranges from 0.005 to 0.05 S/m [5].

3.2.2 Results. First, we evaluated the frequency response of the circuit setting $\phi_z = 0$. Simulation results show that the reactance

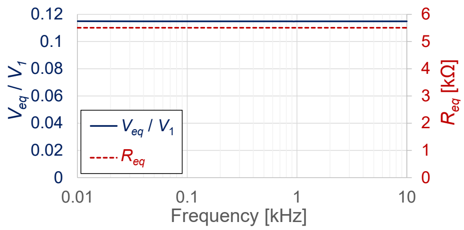

Figure 6: Relationship between circuit constants and frequency.

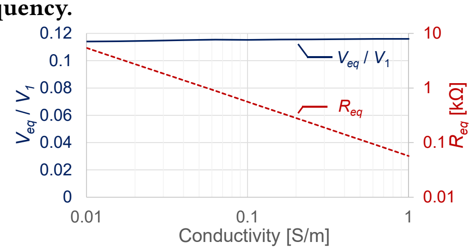

Figure 7: Relationship between circuit constants and conductivity of water.

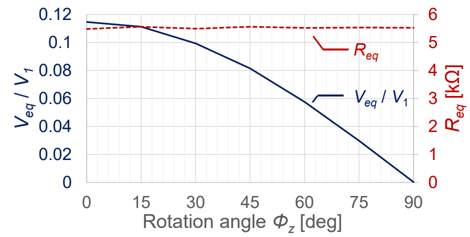

Figure 8: Relationship between circuit constants and rotation angle ϕ_z.

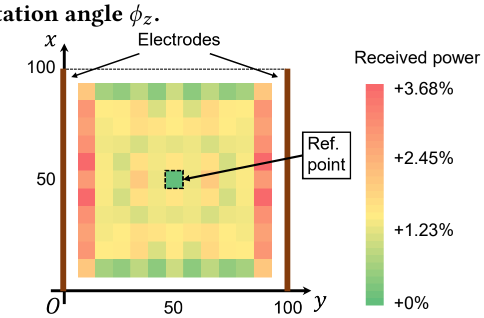

Figure 9: Position dependence of receivable power.

of R_{eq} is almost zero all time, and hence the following results only show the resistance. Fig. 6 indicates that the circuit constants do not depend on the power frequency, meaning that both DC and AC power supply can be used for our WPT method.

Fig. 7 illustrates how the conductivity σ of the water affects the circuit constants. V_{eq}/V_1 does not depend on σ while R_{eq} is inversely proportional to σ. This means that higher σ enables larger power delivery. However, too high σ results in water electrolysis in actual devices, and hence σ should be carefully tuned.

Fig. 8 shows the directivity characteristics of the pixel node. ϕ_z does not affect R_{eq} while V_{eq}/V_1 becomes zero as ϕ_z approaches to 90 [deg]. This result points out that the proposed underwater WPT method has a directivity issue to be resolved, which is one of our future work.

Finally, we evaluate the position dependence of receivable power. As a first step, we placed a pixel node at the center of the aquarium and evaluated the received power P_{ref}. Next, we moved the position of the pixel node in the range of 10 [mm] $\leq x, y \leq$ 90 [mm] and evaluated how much the received power P_{ref} varied keeping $z = 50$ [mm], where the pixel node is assumed to have a 2.3 k Ω resistor. The resistance values is determined based on the datasheet of the MCU [6]. Fig. 9 illustrates the result. When $V_1 = 141$ [V], measured P_{ref} is 4.78 mW, which is sufficient to drive both the MCU and LED. As shown in Fig. 9, even when the pixel node approaches electrodes, the increase in received power is limited to only 3.68 %. Therefore, the position dependence of the proposed WPT method is small.

4 CONCLUSION

This paper presented a scalable and shape-flexible underwater display system. To ensure the flexibility of the display system, we proposed an underwater WPT and wireless communication method which enables pixel nodes to be controlled without any wiring. Evaluation results showed that the proposed WPT method could deliver the power of more than 4.78 mW to a 8mm × 8mm × 8mm size node. Also, the proposed method can retain the communication even when the speed is dropped to 9600 baud.

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REFERENCES

[1] Sean Follmer, Daniel Leithinger, Alex Olwal, Akimitsu Hogge, and Hiroshi Ishii. 2013. inFORM: dynamic physical affordances and constraints through shape and object actuation.. In *Uist*, Vol. 13. 2501–988.

[2] John Hardy, Christian Weichel, Faisal Taher, John Vidler, and Jason Alexander. 2015. Shapeclip: towards rapid prototyping with shape-changing displays for designers. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 19–28.

[3] Yuichi Itoh, Ryo Shirai, Shori Ueda, Taichi Fukamachi, Mayu Yamashita, and Takao Onoye. 2018. 42-2: Invited Paper: OptRod: A Shape-Free and Multi-Functional Display System Operated by Projected Images. In *SID Symposium Digest of Technical Papers*, Vol. 49. Wiley Online Library, 532–535.

[4] Andre Kurs, Aristeidis Karalis, Robert Moffatt, John D Joannopoulos, Peter Fisher, and Marin Soljačić. 2007. Wireless power transfer via strongly coupled magnetic resonances. *science* 317, 5834 (2007), 83–86.

[5] Lenntech. [n.d.]. Water Conductivity. https://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm

[6] Microchip. [n.d.]. PIC10(L)F320/322 Data Sheet. https://ww1.microchip.com/downloads/en/DeviceDoc/40001585D.pdf

[7] Yoichi Ochiai, Takayuki Hoshi, and Jun Rekimoto. 2014. Pixie dust: graphics generated by levitated and animated objects in computational acoustic-potential field. *ACM Transactions on Graphics (TOG)* 33, 4 (2014), 1–13.

[8] 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 *SIGGRAPH Asia 2018 Emerging Technologies*. 1–2.

[9] Ryo Shirai and Masanori Hashimoto. 2021. Submarine LED: Wirelessly powered underwater display controlling its buoyancy. In *SIGGRAPH Asia 2021 Posters*. 1–2.

[10] Ryo Shirai, Yuichi Itoh, Taichi Fukamachi, Mayu Yamashita, and Takao Onoye. 2017. OptRod: operating multiple various actuators simultaneously by projected images. In *SIGGRAPH Asia 2017 Emerging Technologies*. 1–2.

[11] Ryo Shirai, Yuichi Itoh, Shori Ueda, and Takao Onoye. 2018. OptRod: Constructing Interactive Surface with Multiple Functions and Flexible Shape by Projected Image. In *The 31st Annual ACM Symposium on User Interface Software and Technology Adjunct Proceedings*. 169–171.
[12] Yuki Uno, Hao Qiu, Toru Sai, Shunta Iguchi, Yota Mizutani, Takayuki Hoshi, Yoshihiro Kawahara, Yasuaki Kakehi, and Makoto Takamiya. 2018. Luciola: a millimeter-scale light-emitting particle moving in mid-air based on acoustic levitation and wireless powering. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 4 (2018), 1–17.
[13] Zhen Zhang, Hongliang Pang, Apostolos Georgiadis, and Carlo Cecati. 2018. Wireless power transfer?An overview. *IEEE Transactions on Industrial Electronics* 66, 2 (2018), 1044–1058.