BubBowl: Display Vessel Using Electrolysis Bubbles in Drinkable Beverages

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ABSTRACT
Research was conducted regarding a display that presents digital information using bubbles. Conventional bubble displays require moving parts, because it is common to use air taken from outside of the water to represent pixels. However, it is difficult to increase the number of pixels at a low cost. We propose a liquid-surface display using pixels of bubble clusters generated from electrolysis, and present the cup-type device *BubBowl*, which generates a 10×10 pixel dot matrix pattern on the surface of a beverage. Our technique requires neither a gas supply from the outside nor moving parts. Using the proposed electrolysis method, a higher-resolution display can easily be realized using a PCB with a higher density of matrix electrodes. Moreover, the method is simple and practical, and can be utilized in daily life, such as for presenting information using bubbles on the surface of coffee in a cup.

Author Keywords
Bubble display; Electrolysis; Ambient display; Edible.

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);**

INTRODUCTION
Water is indispensable to human life. People enjoy scenery with water and pour drinks into cups every day. In addition to water, bubbles floating on the water are also essential to daily life. The expression and mellowness of the foam that covers the surface of a beverage have enriched the drinking experience for ages. For an example, "latte art" experts enjoy drawing on the foam surface of a cup of coffee. In recent years, attempts have been made to computerize latte art. Ripple-providing devices "print" static characters and images on the foam surface of beverages such as coffee, beer, and cocktails, according to a command from a smartphone application[1]. However, such products cannot provide dynamic information.

[1]http://www.coffeeripples.com

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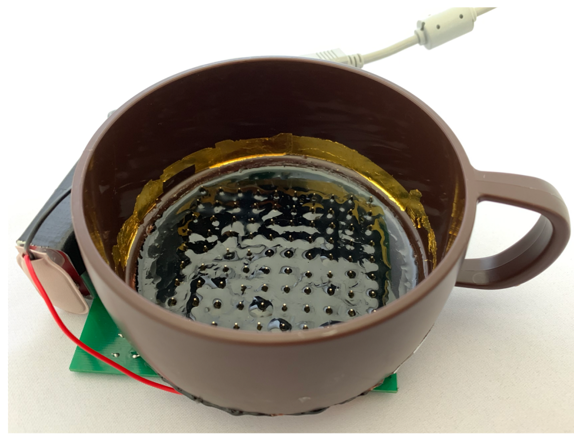

Figure 1. BubBowl without liquid: matrix cathode pins and a common anode plate are placed inside a vessel for liquid

Numerous studies have been conducted to present dynamic information using bubbles. Information Percolator [2] is a display that uses bubbles rising in water. However, this system requires moving parts such as air compressors and electromagnetic valves to supply air from the outside and to control the bubbles. Therefore, it is difficult to increase the number of pixels at a low cost. Water is a chemical compound of hydrogen and oxygen. Therefore, hydrogen and oxygen gases are generated during electrolysis. In this research, we focus on this phenomenon, and propose a liquid-surface display using pixels made of bubble clusters generated by electrolysis. We developed the self-contained cup-type device *BubBowl*, which generates a dot matrix pattern of 10×10 pixels on the surface of beverages and jellies (see Figure 1).

RELATED WORK
There have been several studies on bubble displays that used bubbles themselves as pixels to present information. Information Percolator [2] is a scrolling 2D display using rising bubbles in a group of transparent pipes that are filled with water. The device is designed as an ambient display [15, 4, 1] that attracts user's attention, but only in appropriate and desirable situations. The Information Percolator is designed to be a decorative object that "fades into the background" when not being directly attended to. We also believe that bubbles in a beverage vessel can be a natural ambient display that fades into the background of daily lives. Volumetric Bubble Display [7] is a bubble display capable of high-resolution pixel display. This is a 3D display that uses micro bubbles generated in high-viscosity liquid (e.g., glycerin) by using focused

femtosecond laser pulses. Although the 3D pixels are optically generated without mechanical or electrical components, the refresh rate is very long, because the bubbles stay in the high-viscosity liquid once they are generated. Although our present method also has a slow-refresh problem, the refresh rate is much more acceptable (approximately 10 s). Shaboned Display [3] is a 10 × 10 pixels 2D display that uses soap bubbles as pixels. It has 100 nozzles made of sponge that are dipped in soapy water. Each nozzle has a shape-changing mechanism to create a soap film and is connected to an air pump that generates a soap bubble.

All of the above-mentioned bubble displays require large and expensive parts to generate bubbles. They cannot be embedded into an everyday object such as a coffee cup, because space-constrained, battery-powered wireless implementation remains difficult. Moreover, many existing prototypes require a mechanical moving part for each pixel or column. As the number of pixels increases, the number of required mechanical parts also increases, and the bubble display becomes large and expensive. On the other hand, our system can be small and battery-operated, and can render a display small enough to be embedded in everyday objects, such as a coffee cup. Further, the number of pixels can be increased at a low cost, because the display consists of electrodes and does not require moving parts. Therefore, our proposed method has the potential to realize an ambient display with bubbles that is familiar to daily life and that allows diverse expression.

H_2 Bubble Display[2] is a canvas that generates rising bubbles in a transparent water tank equipped with 8 × 8 pairs of electrodes at the bottom. Although each electrode in the canvas generates gas from electrolysis, the gas is not used to generate pixels but for music-synchronized rising mist with the bubbles. In contrast, our system focuses on round bubble clusters formed on the surface of a colored electrolytic solution (e.g., coffee), and utilizes them as the pixels of dot-matrix computer characters. We also implemented self-contained and compact active-matrix circuits at the bottom of a mug, which enable an information display on the surface of drinkable beverages.

In addition to bubble displays, other kinds of substantial displays using everyday physical materials as pixels have been proposed. For example, Mosaic Textile [14] uses textile as pixels, Dewy [9] and Ketsuro-Graffiti [12] use water condensation, MOSS-xels [5] uses moss, and Tangible Drops [10] uses liquid metal drops. Udayan et al. proposed an interaction with water droplets [13]. User-interaction with displays using a physical material have also been tried in several previous studies. Here, users can interact with pixels utilizing unique features of the material. In Shaboned Display, users can intuitively modify a pixel by bursting the soap bubbles with their fingers. In Ketsuro-Graffiti, users can write graffiti with their fingers on a displayed pattern that uses water condensation. Similar to these systems, intuitive interaction is provided by our system using features unique to bubbles. For example, the proposed system can be designed to receive

[2]http://cargo.jonathanbobrow.com/Bubble-Display

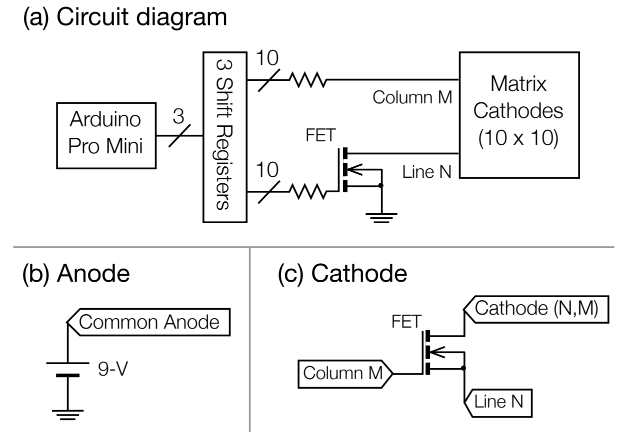

Figure 2. Circuit diagram showing the wiring of Line N and Column M. (N = 1 to 10, and M = 1 to 10)

a user's request to refresh the information when they blow on or drink bubbles in the cup.

Some studies have used soap bubbles as projection screens [8, 6, 11]. Here, an aerial display was achieved by projecting onto floating soap bubbles, and intuitive input was realized by bursting the bubbles or moving a hand nearby. We treat the bubble itself as a pixel. Although a projection mechanism is additionally required, we could also enrich the expression by projecting onto the bubble surface. Bubbles generated by electrolysis with a small electric current are so fine and white that a cluster of bubbles is suitable for projection mechanism.

BUBBOWL

Figure 1 shows an overview of the BubBowl. At the bottom of the liquid vessel, a 10 × 10 matrix of electrodes (cathodes) with intervals of 6.35 mm is fabricated, while a common anode plate is placed around the wall inside the vessel. The overall size of the cathode pin area is 57.2 × 57.2 mm. The cathode pins are composed of off-the-shelf gold-plated pin header parts, and the anode is made of gold leaf to prevent elution via electrolysis.

Matrix circuit

Figure 2 (a) shows the circuit diagram of the BubBowl. The 100 pixel electrodes are connected to an active matrix circuit that is controlled by an Arduino Pro Mini microcontroller board. Each electrode functions as a cathode when the pixel is turned on. We used 3 shift registers for 10 columns, and 10 line wires to reduce the number of necessary output pins to the Arduino board. With control from the Arduino board, a high or low voltage was applied to each of the column wires, and several arbitrary wires out of the 10 were grounded. As discussed later, pixel electrodes received a certain amount of electrolysis current, and a metal-oxide-semiconductor field effect transistor (MOSFET) was used for each switching circuit to increase the acceptable current level. As shown in Figure 2 (b), the positive output of a 9-V battery is connected to the common anode, and the negative output is connected to the common ground. Figure 2 (c) shows the intersection of the matrix circuit where the M-th column and N-th line wires cross. There is a MOSFET and a pixel electrode (cathode) at each intersection of the matrix. The pixel electrode is connected

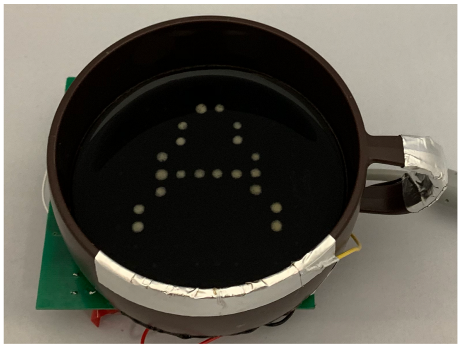

Figure 3. Bubble display example "A"

to the drain of the field effect transistor (FET), the column wire is connected to the gate, and the line wire is connected to the source. When a high voltage is applied to a column wire, and the line wire is connected to the ground, the FET at the crossing is switched on, and the pixel electrode is connected to the ground. Subsequently, the electrode functions as a cathode for electrolysis, and hydrogen is generated from the electrode.

Electrolytic solution

As a feasibility study, a 0.4% solution of sodium bicarbonate in purified water was used as an electrolytic solution. In this situation, the gases generated by the electrolysis of the solution are hydrogen and oxygen. They are safe to inhale, and no by-product is generated. When the system was running, hydrogen was generated from specific cathodes, and it formed round "pixels" of fine bubble clusters on the water surface. However, these bubble clusters were difficult to observe when a colorless and transparent sodium bicarbonate solution was used. We found that a colored solution significantly improved the contrast of the pixels; therefore, the solution was colored by adding instant coffee powder at 16 g/L. As a result, pixels of bubble clusters were easily distinguishable from the background water surface at a height of 1.5 cm, as shown in Figure 3. To improve the display quality by preventing diffusion of the bubbles, we also added a small amount of cornstarch into the warmed coffee, which increased the thickness of the liquid. We found that 1.8 g/L of cornstarch was sufficient to stabilize the bubble clusters. The kinematic viscosity of the viscous coffee was 1.1 mm^2/s. Although oxygen was also generated from the anode around the wall of the vessel, it did not affect the pixel quality, because the oxygen bubbles were thinly formed around the edge of the water surface. All the materials in the vessel (oxygen, hydrogen, water, sodium bicarbonate, instant coffee, and cornstarch) were harmless to humans.

Technical evaluation

Reflecting the arrangement of cathode pins at the bottom, the display size was approximately 6 $\times$ 6 cm, and the interval between pixels was 6.35 mm (4 dpi). In an earlier prototype, we found that a 2.54 mm interval (10 dpi) was also possible on the coffee surface at a liquid height of 8 cm with 1.8 g/L cornstarch.

As our display mechanism turns each pixel on or off by starting or stopping the bubble generation, the response speed was much lower than that of common displays, such as liquid

	Viscous	Non-viscous
Cornstarch (g/L)	1.8	0
Black to light gray (s)	6	6
White to dark gray (s)	$\geqq 60$	12

Table 1. Response time for viscous and non-viscous coffee.

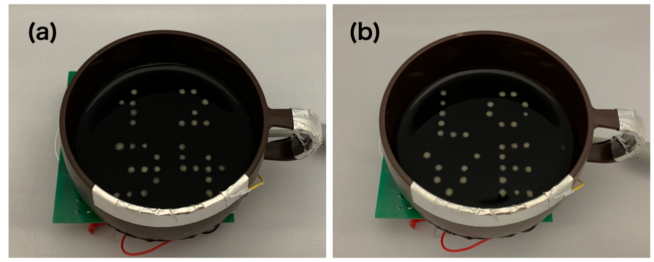

Figure 4. Display examples: (a) Digital clock 12:34; (b) message "LOVE"

crystal displays (LCDs). To evaluate the response time of the display, one of the electrodes was switched on and off, and a video recorded the bubble pixels. The current applied to the electrode was 0.65 mA, and the water level of the solution was 1.5 cm. Table 1 shows black-to-light-gray (BTG) and white-to-dark-gray (WTG) response times for a viscous solution with cornstarch, and a non-viscous solution without cornstarch, respectively. The BTG response time was the time lapse between black and 80% of the maximum lightness by generating bubbles, and the WTG was the time lapse between white and 40% black by the fading of the bubbles. As demonstrated by the WTG result, it took a long time before the bubbles disappeared spontaneously, especially when the solution was viscous. If a shorter disappearance time is required, a user breathing on the liquid surface, or a small electric fan could erase the bubbles quickly.

APPLICATIONS

In this section, we introduce some bubble display applications that use the advantages of our proposed mechanism.

Ambient display

Some people decorate their living spaces with shallow flower containers for flower arrangements, or with a miniature pond or fountain. The proposed system can be used as an ambient display for these decorations, because it generates bubble pixels on a water surface at low-cost, and it is compact and has a silent mechanism. On a water surface in a living space, it is possible to display an ambient digital clock using bubbles (see Figure 4(a)). It is also possible to present any message up to four characters long (see Figure 4(b)).

Information beverage

The mechanism of our bubble generation is simple and small enough that it can be embedded in the bottom of cups, mugs, and bowls to display information on the surface of drinkable beverages. For the evaluation, we used instant coffee and water with sodium bicarbonate and cornstarch[3]. All the materials

[3]The taste is almost indistinguishable from that of the additive-free coffee.

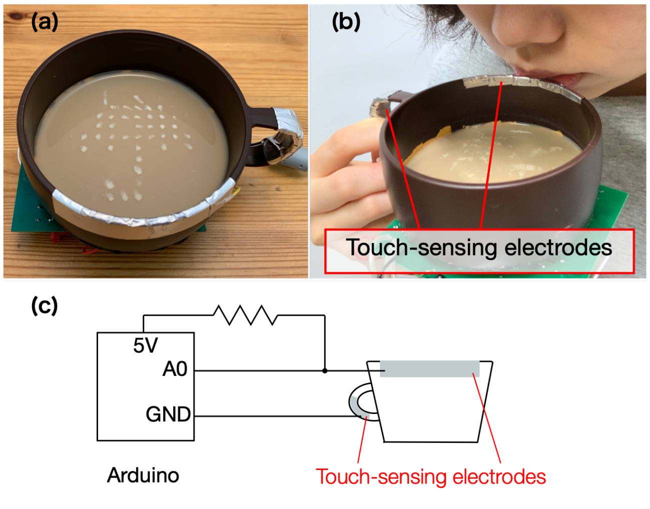

Figure 5. (a) Weather report (rain) on cafe au lait; (b) drinking action is detected by finger and mouth touch; (c) circuit diagram

are harmless to humans, and they do not generate toxic gases[4] during electrolysis. Moreover, we used pure gold foil for the anode, and it does not elute through electrolysis. Therefore, there is nothing dangerous to drink included in the liquid. Besides coffee, other beverages such as tea, cocoa, milk, and juice can safely be used for the bubble display. Figure 5(a) shows an example of a bubble display using cafe au lait (milk and instant coffee) as an electrolytic solution. This cafe au lait contained a 0.4% concentration of sodium bicarbonate to promote electrical flow. Fruit juice is a more ideal material for a bubble display, because it is conductive, and no additives such as sodium bicarbonate are necessary. We also tested 100% orange juice and grape juice, with which a clear display with bubble clusters was obtained.

Because the system applies an electric current to a beverage, drinking the beverage while running the system carries the potential for causing an electrical shock. This risk can be eliminated by adding a safety circuit that immediately stops the electrolytic current when a user attempts to drink the beverage. Accordingly, we attached a pair of touch-sensing electrodes at the outside and the edge of the mug to detect drinking action, as shown in Figure 5(b). When a user tries to drink the beverage, the user's finger and mouth touch these electrodes simultaneously. Figure 5(c) shows the circuit diagram for detecting the drinking action. When the user's finger and mouth touch the electrodes, the voltage applied to the Arduino analog input pin is reduced. Although a simple tilt switch could also have been used for drinking detection, we wanted to allow the users to see the display while they held or slightly tilted the cup.

Food printing

Some raw food material is liquid or paste. Hence, we can generate bubbles before the food is cooked, and print information on the food. Figure 6 shows grape jelly with the message ("LOVE") printed using bubbles on the surface.

[4]No ozone is generated using the current setup. Chlorine is generated when the beverage includes salt.

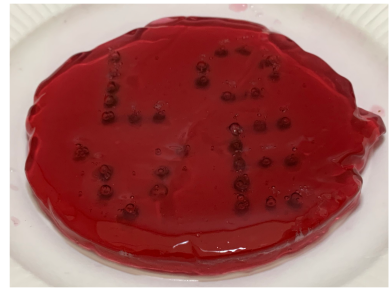

Figure 6. Grape jelly with the message "LOVE"

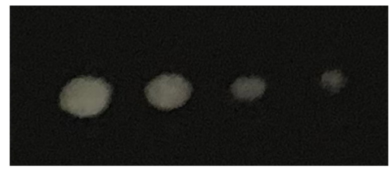

Figure 7. Four grayscale pixels

We made it by mixing agar with 100% grape juice and electrolyzing it while it cooled in a refrigerator. The jelly is edible, because the electrolytic solution used is harmless to the human body. In addition to jelly, we believe that baked confections that carry messages using bubbles can be made by electrolyzing with crepe or hotcake dough.

We also believe that it is possible to generate 3D objects using bubbles by solidifying the electrolytic solution from the surface. We are considering 3D bubble printing inside jelly by cooling and solidifying it from the top to the bottom while generating bubbles. Likewise, we believe that 3D objects can be created using bubbles confined in ice by freezing the solution from the surface downward. These objects should be edible if a solution harmless to the human body is selected.

Grayscale display

The proposed system can display binary and grayscale images. A grayscale display can be achieved by adjusting the time for which the electrodes (cathodes) are grounded. Figure 7 shows bubbles generated from four electrodes with different ground contact times. They are grounded from the right for 10, 20, 30, and 40 s, and the applied current is 0.17 mA for each electrode. Considering that Daniel Rozin's Wooden Mirror[5] displays an image of the face of a person who views the system with approximately 30 $\times$ 30 pixels, we are planning to increase the number of pixels to approximately 1,000 to display natural grayscale images.

CONCLUSION

In this study, we proposed a liquid-surface display using bubble clusters generated by electrolysis and developed a cup-type system called BubBowl that generates a dot matrix pattern with 10 $\times$ 10 pixels on the surface of a beverage. Our future work will be to increase the number of pixels, resolution, and grayscale levels, so that a greater diversity of expressions can be achieved. We are also planning to implement applications such as 3D jelly printing and an interactive bubble display.

[5]http://www.smoothware.com/danny/woodenmirror.html

REFERENCES

[1] Andrew Dahley, Craig Wisneski, and Hiroshi Ishii. 1998. Water Lamp and Pinwheels: Ambient Projection of Digital Information into Architectural Space. In *CHI 98 Conference Summary on Human Factors in Computing Systems (CHI '98)*. ACM, New York, NY, USA, 269–270. DOI: http://dx.doi.org/10.1145/286498.286750

[2] Jeremy M. Heiner, Scott E. Hudson, and Kenichiro Tanaka. 1999. The Information Percolator: Ambient Information Display in a Decorative Object. In *Proceedings of the 12th Annual ACM Symposium on User Interface Software and Technology (UIST '99)*. ACM, New York, NY, USA, 141–148. DOI: http://dx.doi.org/10.1145/320719.322595

[3] Shiho Hirayama and Yasuaki Kakehi. 2010. Shaboned Display: An Interactive Substantial Display Using Soap Bubbles. In *ACM SIGGRAPH 2010 Emerging Technologies (SIGGRAPH '10)*. ACM, New York, NY, USA, Article 21, 1 pages. DOI: http://dx.doi.org/10.1145/1836821.1836842

[4] Hiroshi Ishii, Craig Wisneski, Scott Brave, Andrew Dahley, Matt Gorbet, Brygg Ullmer, and Paul Yarin. 1998. ambientROOM: Integrating Ambient Media with Architectural Space. In *CHI 98 Conference Summary on Human Factors in Computing Systems (CHI '98)*. ACM, New York, NY, USA, 173–174. DOI: http://dx.doi.org/10.1145/286498.286652

[5] Takaki Kimura and Yasuaki Kakehi. 2014. MOSS-xels: Slow Changing Pixels Using the Shape of Racomitrium Canescens. In *ACM SIGGRAPH 2014 Posters (SIGGRAPH '14)*. ACM, New York, NY, USA, Article 20, 1 pages. DOI: http://dx.doi.org/10.1145/2614217.2630572

[6] Yuki Kubo, Hirobumi Tomita, Shuta Nakamae, Takayuki Hoshi, and Yoichi Ochiai. 2016. Bubble Cloud: Projection of an Image Onto a Bubble Cluster. In *Proceedings of the 13th International Conference on Advances in Computer Entertainment Technology (ACE '16)*. ACM, New York, NY, USA, Article 41, 4 pages. DOI:http://dx.doi.org/10.1145/3001773.3001815

[7] Kota Kumagai, Satoshi Hasegawa, and Yoshio Hayasaki. 2017. Volumetric bubble display. *Optica* 4, 3 (2017), 298–302. DOI: http://dx.doi.org/10.1364/OPTICA.4.000298

[8] Masahiro Nakamura, Go Inaba, Jun Tamaoki, Kazuhito Shiratori, and Junichi Hoshino. 2006. Mounting and Application of Bubble Display System: Bubble Cosmos. In *Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology (ACE '06)*. ACM, New York, NY, USA, Article 47. DOI: http://dx.doi.org/10.1145/1178823.1178879

[9] Amanda Parkes and Dietmar Offenhuber. 2007. Dewy: A Condensation Display. In *ACM SIGGRAPH 2007 Posters (SIGGRAPH '07)*. ACM, New York, NY, USA, Article 44. DOI: http://dx.doi.org/10.1145/1280720.1280769

[10] Deepak Ranjan Sahoo, Timothy Neate, Yutaka Tokuda, Jennifer Pearson, Simon Robinson, Sriram Subramanian, and Matt Jones. 2018. Tangible Drops: A Visio-Tactile Display Using Actuated Liquid-Metal Droplets. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 177, 14 pages. DOI: http://dx.doi.org/10.1145/3173574.3173751

[11] Sue Ann Seah, Diego Martinez Plasencia, Peter D. Bennett, Abhijit Karnik, Vlad Stefan Otrocol, Jarrod Knibbe, Andy Cockburn, and Sriram Subramanian. 2014. SensaBubble: A Chrono-sensory Mid-air Display of Sight and Smell. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2863–2872. DOI:http://dx.doi.org/10.1145/2556288.2557087

[12] Yuki Tsujimoto, Yuichi Itoh, and Takao Onoye. 2016. Ketsuro-Graffiti: An Interactive Display with Water Condensation. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces (ISS '16)*. ACM, New York, NY, USA, 49–55. DOI:http://dx.doi.org/10.1145/2992154.2992159

[13] Udayan Umapathi, Patrick Shin, Ken Nakagaki, Daniel Leithinger, and Hiroshi Ishii. 2018. Programmable Droplets for Interaction. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (CHI EA '18)*. ACM, New York, NY, USA, Article VS15, 1 pages. DOI: http://dx.doi.org/10.1145/3170427.3186607

[14] Akira Wakita and Midori Shibutani. 2006. Mosaic Textile: Wearable Ambient Display with Non-emissive Color-changing Modules. In *Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology (ACE '06)*. ACM, New York, NY, USA, Article 48. DOI: http://dx.doi.org/10.1145/1178823.1178880

[15] Craig Wisneski, Hiroshi Ishii, Andrew Dahley, Matt Gorbet, Scott Brave, Brygg Ullmer, and Paul Yarin. 1998. Ambient displays: Turning architectural space into an interface between people and digital information. In *Proceedings of Cooperative Buildings: Integrating Information, Organization, and Architecture (CoBuild 1998)*. Springer, Berlin, Heidelberg, 22–32. DOI: http://dx.doi.org/10.1007/3-540-69706-3_4