Poppable Display:

A display that enables popping, breaking, and tearing interactions with people

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***Abstract*—We previously developed a display using a soap film as a screen. This screen can display various appearances of the projected images by changing its reflectance property by controlling ultrasound waves. Further, the soap film has other advantages of being very thin and disposable. This research aims to make use of these advantages to realize new interactions with a display. The soap screen pops out and breaks. Users can insert their fingers into the screen. When the screen breaks, it can be replaced easily. This display is expected to contribute to entertainment computing communities by acting as a deformable and physically interactive display. In this paper, the details of the proposed display, the related experimental results, discussion and future work are presented.**

Keywords—Entertainment; Interaction Design; Virtual Reality / Mixed Reality.

I. INTRODUCTION

Screens are essential to entertainment as they display various digital contents such as movies, presentations, and shows. Typical screens are rigid and static, and allow no physical user interaction corresponding to the displayed contents. In this research, we attempt to enable physical interactions with a display. A colloidal screen [1] (shown in Figure 1) is expanded to be “poppable” for this purpose. The transparency of the colloidal screen is controlled by ultrasound waves, and the screen is deformed by changing the intensity of these waves.

We propose to add a “physical effect” in display interaction and entertainment computing using this technology. “Pop” and “deform” interaction on display has a potential to computer entertainment. There are many “analog” toys and games that pops balloons, deform images, and break something. These games and toys have surprise and amusement. Poppable display is a digital display that enables such physical interactions: popping, deforming, and breaking. Adding to that, these physical effects are repeatable by replacing the soap films. Soap films are unique material which allows the object to pass through (shown in Figure 2). Digital toys might be applicable soon with a portable projector and there are a lot of toys using soap bubbles. This research will contribute to combine the essential enjoyment of soap bubbles and computer entertainment.

II. RELATED WORKS

A. Deformable Screen

Most deformable screens aim at providing visible contents with tactile feedback [2] [3]. These deformable screens make three-dimensional (3D) forms on the surface of the screen by using the actuator array set under the screen. Such systems have a hard screen on the actuator array and are different from the proposed display system from the perspectives of disposability or replacement of the screen.

Further, several studies have been conducted on flexible displays such as FlexPad [4]. According to these studies, a flexible display can be bent by a user or it can twist itself. However, they do not discuss the disposability or the breaking interaction of the screen. Adding to that, Splash Display [5] reports the splashing interaction of projectile beads. However it is not used for stable and deforming images.We believe that the property of being “poppable” should be added to enhance user interactions with a flexible display.

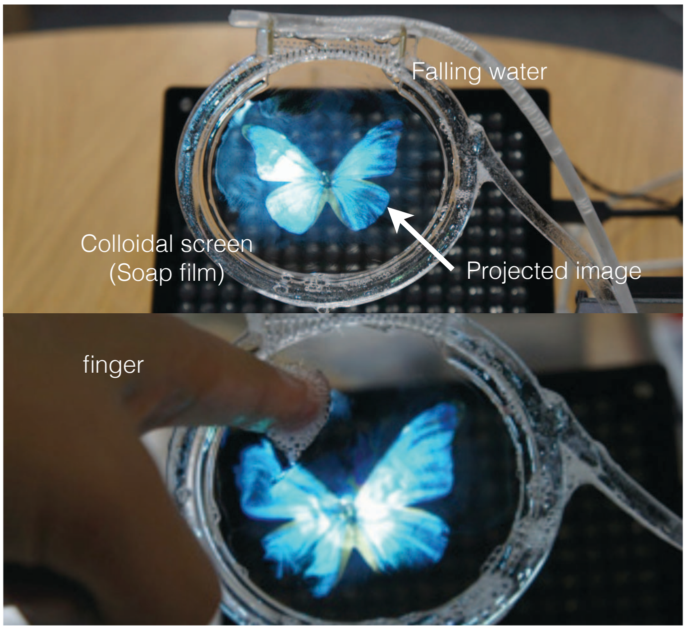

Figure1: Overview of poppable display.

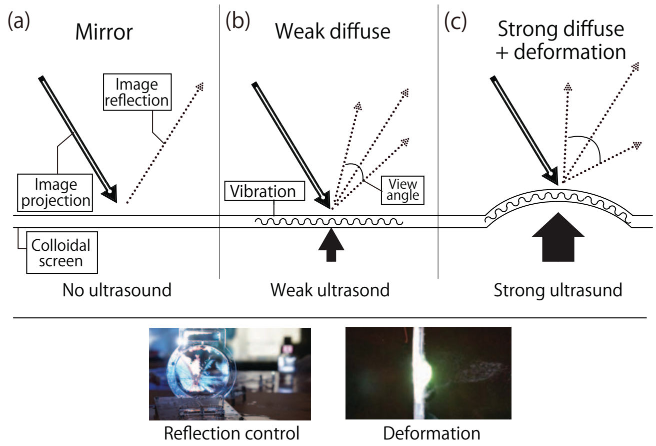

Figure2: Relationship between ultrasounds and colloidal screen.

B. Bubble Display

There are several displays that use soap bubbles. Bubble Cosmos [6] is a technology through which a screen is created in air by confining fog in a bubble. However, it does not utilize the popping property of the bubbles. Further, while Shaboned Display [7] detects the popping of the bubble pixels, it is not a projection screen. This research on poppable display, have physical visual effect and interaction on projection screen.

III. POPPABLE DISPLAY

A. Images on the screen

In our previous research [1] on colloidal displays, a plane ultrasound wave was used for exciting a soap film. When the soap film was excited, it becomes a flexible projection screen and its reflection characteristic could be controlled. An ordinary soap film is like a mirror, and the projected images cannot be seen on it (Figure 2(a)). However, it becomes diffused depending on the intensity of the ultrasound wave and then acts as a projection screen (Figure 2(b)).

The diffusion on the ultrasound-activated colloidal film seems to be caused by the capillary waves which is dominated by surface tension[8]. Dispersion relation of the waves on interface is described by Equation (1) [9].

$$\lambda = \left(\frac{8\pi\sigma}{\rho f^2}\right)^{\frac{1}{3}} \tag{1}$$

where σ is the surface tension, ρ is the density of the colloidal solution and f is the excitation frequency. Wavelength λ is estimated from Equation (1). The surface tension of colloidal liquid σ is 0.07275 N/m (20 deg C). Suppose the surface tension of colloidal liquid to be 1/2 of water and density to be the same as water 1000kg/m^3. In this situation, with 40kHz ultrasounds, the wavelength λ is 2π/k=83μm.

Then it is supposed that such minute waves (Figure 3) occurs on the ultrasound-activated colloidal film and they diffuse the light on the surface.

In order to create a poppable and deformable screen, a focused (high-intensity) ultrasound wave is used instead of a plane one (Figure 2(c)).

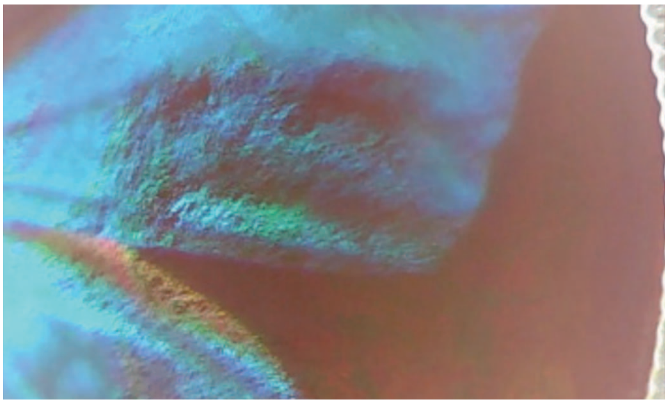

Figure3: Enlarged view of colloidal screen.

B. Ultrasonic waves

A phased array focusing technique is used for achieving a high-intensity ultrasound wave. The focal point of the ultrasound wave is generated by setting adequate phase delays of multiple transducers. Further, the focal point can be moved to an arbitrary position by controlling the phase delays [11].

The acoustic radiation pressure, which is a nonlinear phenomenon of an ultrasound wave, acts when the ultrasound wave becomes a high-intensity wave. When an ultrasound beam is reflected vertically at the soap film, it is subjected to a constant vertical force in the direction of the incident beam. Assuming a plane wave, the acoustic radiation pressure P [Pa] is described as follows:

$$P = \alpha E = \alpha \frac{p^2}{\rho c^2} \tag{2}$$

where c [m/s] denotes the sound speed; p [Pa], the RMS sound pressure of the ultrasound waves; and ρ [kg/m^3], the density of the medium. α denotes the constant depending on the reflection coefficient of the soap film and is equal to 2 in the case of total reflection [12].

The focal point of ultrasound is generated by setting adequate phase delays of multiple transducers. In addition, the focal point can be moved to an arbitrary position by controlling the phase delays. The spatial resolution and the array size are in the relationship of trade-off. It is theoretically derived that the spatial distribution of ultrasound generated from a rectangular transducer array is nearly sinc-function

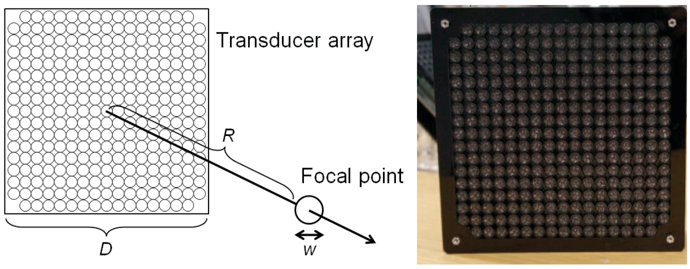

Figure4: Illustration (left) and photo of phased array (right)

Table 1: Specifications of components

Projector	LCD/DLP/Laser	
Screen	Colloid solution	Soap
	Size of membrane	8cm in diameter
Ultrasound	Transducers	285pics
	Frequency	40kHz
	Focus control	Phased Array
	Size of focal point	2cm at distance of 20cm distance

shaped [12]. The width of the main lobe (w [m]) is parallel to the side of the rectangular is written as

$$w = \frac{2\lambda R}{D} \tag{3}$$

where λ [m] is the wavelength, R [m] is the focal length, and D [m] is the side length of the rectangular array (Figure 4).

IV. IMPLEMENTATION

A. System Overview

A poppable display has four components: a projector; a tank of soap solution; a frame; and the mechanism to replace the film, an ultrasonic excitation device.

Figure 5 shows one of the configurations that uses these components. The projector light is focused on the film and the film's frame. Ultrasound waves are produced from the speaker simultaneously and hit the film, vibrating it. Then the image is projected on the colloidal screen.

A higher-intensity ultrasound wave pops out and breaks the film. When the film is broken, it is replaced by the servomotors.

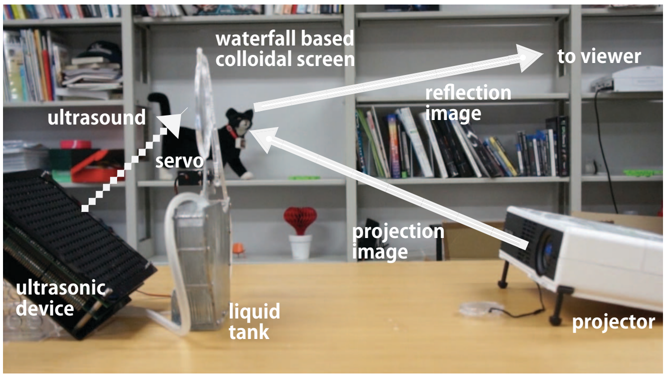

Figure5: System components of poppable display: Ultrasound focusing device set on the opposite side of projector. Image on the screen can be seen only from the projector side.

B. Specification in detail

The specifications of each parts are described in Table 1. LCD, DLP, and Laser projector are available for the poppable display. Colloidal solution for our screen is a bubble liquid (Antari BL-5). Size of the membrane is typically 8cm and the maximum size is 1 meter. Larger membrane have a shorter lifetime. Colloidal screen can be replaced in 5 seconds. View angle is wider than the previous work: 40 degrees [1] to 160 degrees [10]. Waterfall-based frame [10] maintains the colloidal screen to last longer. Water supply system (shown in Figure5) supplies the colloidal solution from the water tank to the frame continuously using a pump.

The detailed specifications of the phased array are as follows. It consists of 285 transducers arranged in a 170 × 170 mm2 square area and designed to generate a single focal point by adequate control of their phase differences. The resonant frequency was 40 kHz, and the sound pressure at the peak of the focal point was as high as 2600 Pa (RMS) when the focal length was 200 mm. The spatial resolution of the position of the focal point was 0.5 mm, and the refresh rate was 1 kHz.

The angle to hit the colloidal film can be ranged from 0 degree (vertical to colloidal film) to 60 degrees. Projector must

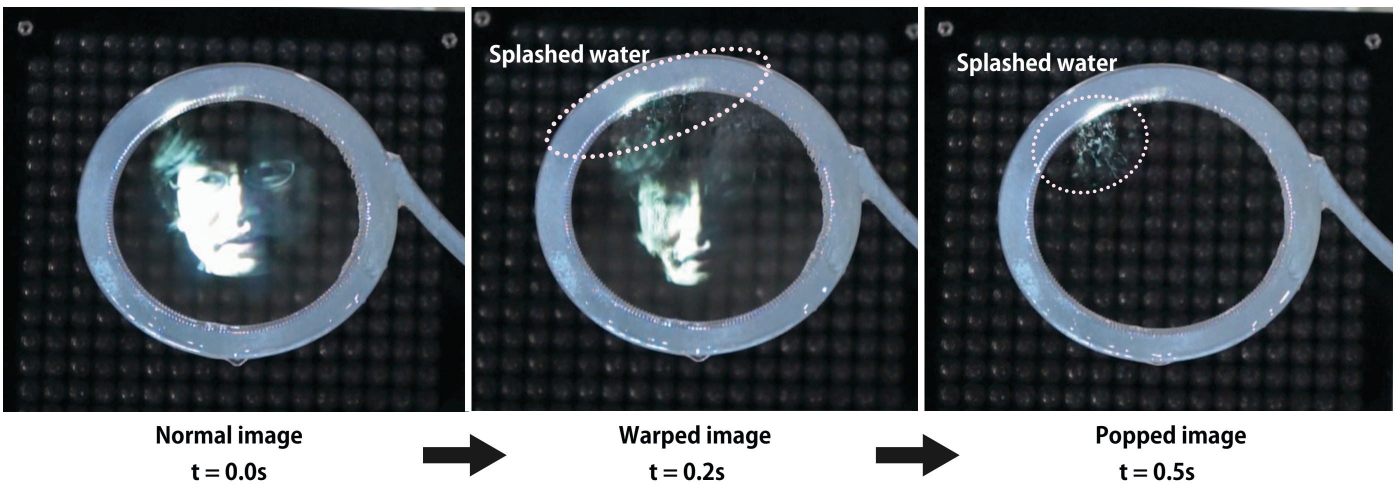

Figure6: Image popping. When the ultrasonic focal points hits the membrane, image on the bubble screen is warped and membrane splashes the water. After that, bubble screen pops in 0.3-2 seconds.

Figure7: Knife cutting the screen

be set on viewer's side and the projected image can only seen on the same side of the projector.

V. Physical Effects & Interactions

A. Popping image

In this system we propose physical and visual effect of popping. We can pop the bubble screen by focusing the ultrasonic waves in high intensity. In Figure 6 (shown in previous page) we show how it pops.

When the ultrasonic focal points hits the membrane, image on the bubble screen is warped and membrane splashes the water. After that, bubble screen pops in 0.3-2 seconds. It is faster to break when the focal point hits the membrane around the edge of the frame. This system replaces the membrane in 5 seconds.

This physical effect can be applied to games, especially using this system as a target. Moreover, it enhances the effect of video projection such as bumping or bursting.

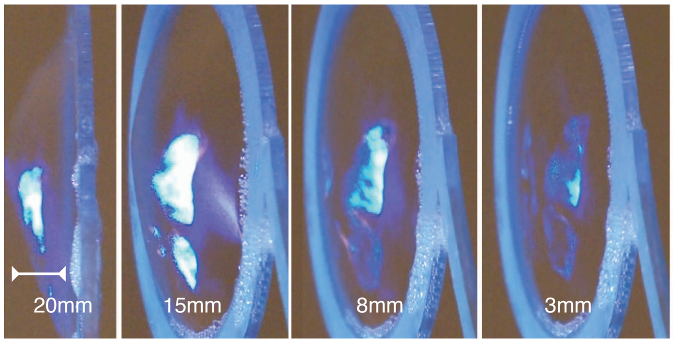

Figure9: Deformation of the screen of up to 20mm.

B. Insert object into the image

Soap film is an unique material which allows the object to pass through it. In Figure 7 we show a knife cutting into the screen. The object must be wet. Ultrasonic focal point should be set at far opposite side of the frame.

This interaction can be expanded in the future to allow the user to literally cut the screen. Further more, this system propose interaction such as tearing, breaking and sticking with screens.

If the object is wet enough, it does not affect the membrane's lifetime..

C. Deforming Animation

In this system we propose deforming animation. We can deform the bubble screen by moving the focal point of the ultrasonic wave. In Figure 8, we show how it can deform the face that is projected.

This physical effect can be applied to many entertainment such as imitating a force field. Moreover, by projecting the face image, it has a potential to enhance the chat's communication or interaction by deforming the screen

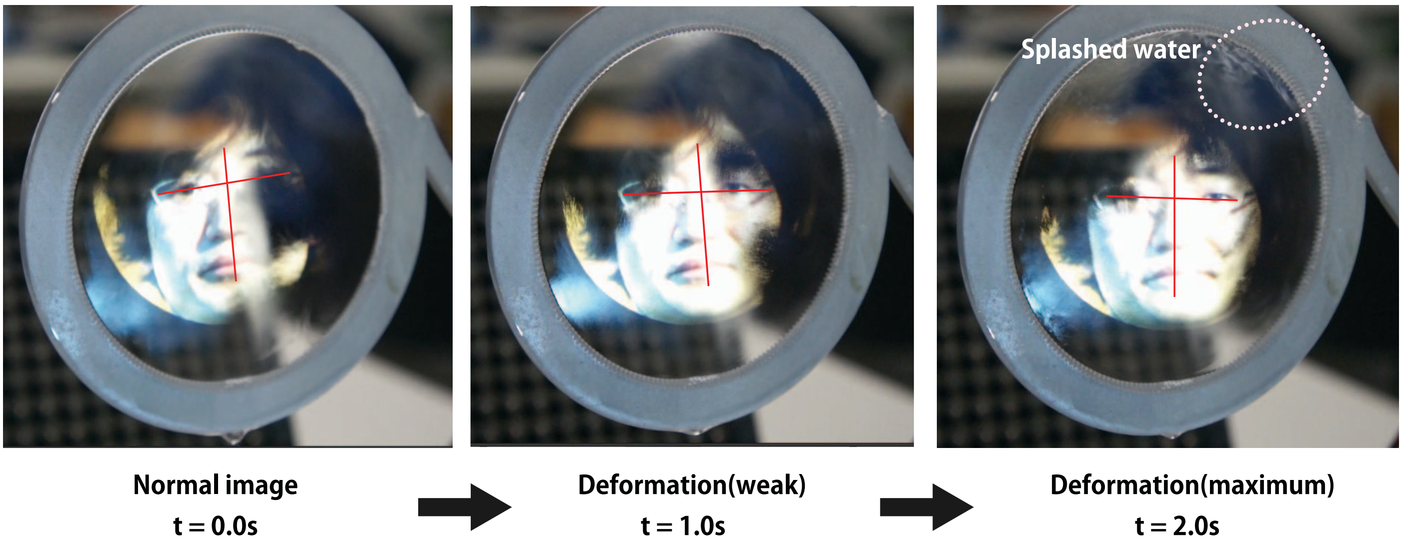

Figure8: Image Deformation. The focal point moves back side of screen to front side. Red lines indicate the deformation of screen. Red lines connect eye to eye and nose to mouse.

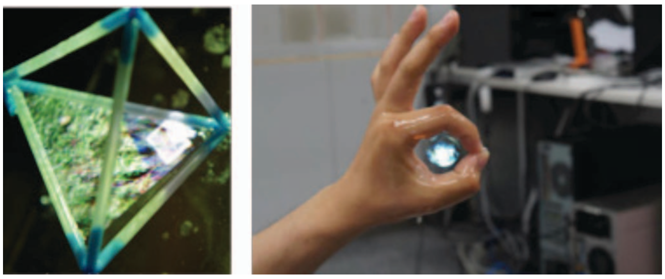

Figure10: Polygon frame and hand frame

Screen deformation shortens the membrane's lifetime. However, by using the waterfall frame the membrane's lifetime will be longer.

VI. Experimental Result

We tested our system using three experiments: measurements of the lifetime of the film, success rate of breaking the film, and the maximum height of the bump of the film. Instruments setup is shown in figure 5 (in previous page 3).

In our experiment, on average, the soap film maintained a stable membrane for 1–3 min according to the intensity of the applied ultrasonic wave. Note that focused ultrasonic device emits a stronger waves than the one in previous work. Intensity is set to maximum.

The success rate of breaking the soap film was 100%. Average breaking time is 1.5 seconds. The breaking time depends on the amount of the water that membrane contains. In this experiment, we tested the membrane soon after the replacement.

The maximum height of the bump was 20 mm (as shown in Figure 9) for the 8cm frame. It depends on the frame size and angle of hitting ultrasounds. In this experiment, we set the ultrasonic focal point at the center of the membrane.

VII. Discussion & Future work

A. Limitation

Soap film's durability depends on the power of the ultrasonic speakers and soap product. Also small disturbance like wind and humidity in the room will affect it. In our experiment, soap film by itself can lasts on average 1-3 minutes according to the intensity of the applied ultrasonic wave. This factor has increased by having a pump that will continue to provide the solution to the frame.

When turning a transparent soap film into opaque, there are some spots that are not covered remaining to be transparent. The area of coverage is roughly 95 percent. Typically the outer rim is transparent because the frame is blocking the ultrasonic waves. However, this coverage is heavily relies on the speaker and the frequency, which makes it hard to evaluate.

B. Future work

A soap film is an unique flexible film which could be applied to any shape of frame. The enjoyable characteristic of a soap bubble has an impact on entertainment computing. Moreover, we can control the spatial position of the ultrasonic focus point and deform the screen partially. This display has the potential of multipoint deformation.

Furthermore, it will be interesting to see a 3D model made out of soap film on a polygon shaped frame (Figure 10) with several ultrasonic devices.

VIII. Conclusion

In this study, we proposed a new method for interaction with a colloidal screen that can control the breaking or deformation of the display by using focused ultrasonic waves.

Further, we confirmed that the proposed method works successfully and discussed on the limitation and future work.

Acknowledgement

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