# Visualizing Water Flows with Transparent Tracer Particles for a Surround-Screen Swimming Pool

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## ABSTRACT

A surround-screen swimming pool can realize various forms of underwater entertainment and enable enhanced swimming training with supplemental visual information during underwater activities. However, one of the big challenges for such an augmented swimming pool is user interaction because the surround screen and water can make existing position-tracking methods unusable. In this paper, we propose a water flow visualization method with transparent tracer particles to enhance interactivity. We used an optical property of clear plastics called birefringence that provides vivid colors on transparent tracer particles when they are between two circular polarization sheets. Tracing objects using cameras in front of a complex background is not a stable method, but this technology enables visible tracer particles on a simple and dark background. For underwater entertainment, the water flow tracing works as a user interface because the transparent tracer particles do not stop users from viewing the images on the screen. For enhanced swimming training, swimmers can view visualized water flow caused by strokes in the augmented swimming pool. From the results of our stability evaluation of water flow tracing, the proposed method is valid even for complex backgrounds. We also conducted a feasibility test of the enhanced swimming training. According to the trial, the tracing particles could visualize the water flow caused by the strokes made by a swimmer.

## Keywords

Swimming; Augmented Sports; Water Flow Visualization; Underwater Entertainment



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**Figure 1: Surround-screen swimming pool for underwater entertainment and enhanced swimming training.**

## 1. INTRODUCTION

Moderate exercise is useful in maintaining our physical fitness. Swimming is a healthy activity widely enjoyed by many people. In general, people swim in a swimming pool, but it is sometimes problematic to stick to a workout routine. One of the reasons is that repeating the same activity in the same place tends to be dull. Swimming in a pool involves constantly repeating monotonous motions in less diversified scenery.

Therefore, we introduced an augmented swimming pool where the entire view of the user is surrounded by synthetic images (Figure 1). With this configuration, the user can enjoy a swimming experience as if he or she were swimming in a real sea with coral reefs. This configuration can provide users with an enhanced swimming experience.

To provide underwater entertainment, user interfaces to interact with the system are required. However, existing devices for this purpose (such as game controllers and vision-based sensors) are difficult or impossible to use in a surround-screen swimming pool [25]. Moreover, position tracking devices using Infrared (IR) are not functional owing to IR absorption by the water [6]. Devices using visible light do not work reliably in the surround-screen environment when displaying complex images [30].

In this paper, we describe a polarization-based technique to put water flow tracing in practice in the surround-screen swimming pool. This water flow tracing technology enables a user interface for underwater entertainment. For example, the user is able to move computer-generated characters in the scene by water flow. The user may also change the setting of the system by causing predetermined directions of water flow in the swimming pool. In addition, for swimming training, swimmers can view visualized water flow caused by strokes in the swimming pool.

Water flow tracing can be realized by using tracer particles scattered in the water [19]. Cameras track the movement of the particles in the water to measure the water flow. However, tracer particles used in previous studies are not preferable for the augmented swimming pool because the particles stop users from viewing the content on screen. Therefore, we propose transparent plastics as tracer particles. The tracing particles show vivid colors on the surface when they are between two polarizing sheets. Thus, the particles enable water flow tracing that does not interfere with the underwater entertainment.

## 2. RELATED WORK

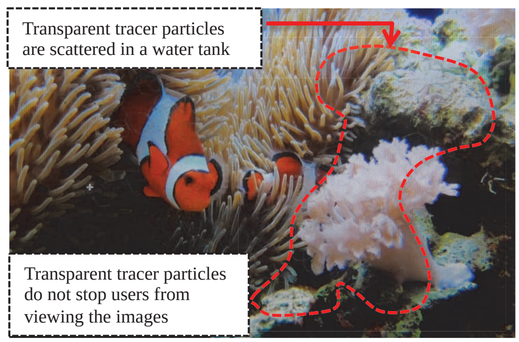
Surround-screen environments are widely used for entertainment and collaboration in other research works. The Cave Automatic Virtual Environment is a surround-screen projection-based virtual reality environment [7, 31]. There were several attempts using this system to enhance product development [9, 15] and games [13]. Therefore, it is known that a surround-screen environment can enhance the entertainment experience and improve the efficiency of learning. However, the capability of this environment in the water has not been studied. In this research, we introduce an underwater surround-screen swimming pool and evaluate its capability.

The AquaTop Display enables underwater entertainment by detecting the user's body movement in a bath [17], but this system cannot be used as a swimming training environment because the water must be white to display images from a projector on the water surface.

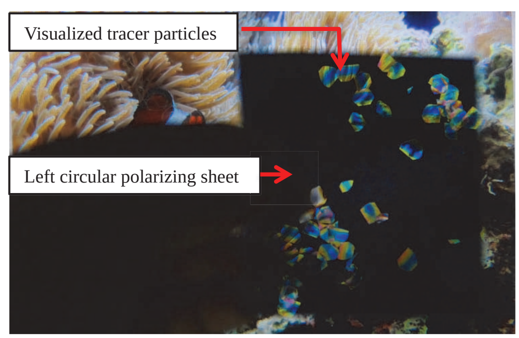
Morales proposed a system with a hand-held augmented reality display for supporting divers [20]. Ukai et al. proposed a swimming support system using an underwater robot that swims with a user and shows information via an attached underwater display [29]. This might be useful for swimming training. However, these displays are mainly used for providing information, and the size of the display is limited. For this reason, it is still difficult to cover a users' entire view as in the case of entertainment.

For fluid measurement, tracer particles or tufts [12] are widely used. Fluid visualization methods such as Particle Image Velocimetry [1] and Laser Doppler Velocimetry [14] use lasers to illuminate the measurement environment to make the particles visible. These methods are not suitable for the surround-screen environment because the illumination itself and visible tracer particles interfere with the user's ability to view the screens. Therefore, we introduce a method to provide a clear view and achieve water flow visualization using lights only from screens. PhotoelasticTouch achieves a user interface in front of a display using the photoelastic effects of soft plastics [26, 24]. A user grabs a lump of clear and soft plastic with his or her fingers and places it in front of a display. The system detects the user's pinches and the positions by measuring the changes in the polarization property of the plastic. However, this measurement method is unusable for tracing particles because the stress applied to the plastic is not caused by water.

There has been some research on swimming motion simulations [16, 5]. Motion simulation from actual captured data may enable water flow estimation, but accurate motion capture is quite challenging in the surround-screen environment. There have been attempts to improve the efficiency of the swimming motion. Tan et al. proposed a system to improve the swimming form of an underwater robot fish by using water flow visualization [27]. Nakashima et al. conducted research, using an underwater robot arm, on unsteady fluid forces acting on limbs in swimming [23]. However, water flow visualization in a swimming environment with humans has not been achieved. There exist several methods to measure swimming form using sensors such as wearable sensors [2] and underwater motion-capture systems [4]. Nevertheless, showing captured information to a swimmer in real time is still an issue because wireless communication between the device and a computer in water is quite challenging [21], and motion capture in a complex background is not always stable [30].




(a) Transparent tracer particles are distributed in a water tank in front of a screen coated with right circular polarizing sheets.




(b) Transparent tracer particles seen through a left circular polarizing sheets. The transparent tracer particles do not stop users from viewing the images on the screen, but are clearly visible for a camera for tracking.

**Figure 2: Transparent tracer particles in the water. The particles show vivid color when placed between tow polarizing sheets. This figure shows a result when the screen is coated with right-handed circular polarizing sheets. [1].**

## 3. WATER FLOW TRACING WITH TRANSPARENT TRACER PARTICLES

We implemented water flow visualization and tracing technology for underwater entertainment and enhanced swimming training. To visualize the water flow in a surround-screen swimming pool, we scattered tracer particles in the water. The tracing particles were made of plastic and were transparent in the water. However, the tracing particles showed vivid color when we observed them in front of a right-handed circular polarizing sheet through a left-handed circular polarizing sheet. Simultaneously, the background images became dark owing to the light shielding caused by the combination of left- and right-handed circular polarizing sheets. This enables us to provide the user a constantly clear view of the displayed content in the pool, and stable visible-light-based water flow tracing as user interfaces. Figure 2 (a) shows scattered transparent tracer particles in a water tank in front of a display coated with a right-handed circular polarizing sheet. Figure 2 (b) shows the visualized tracer particles by a left-handed circular polarizing sheet.

### 3.1 Surround-Screen Swimming Pool

In a surround-screen swimming pool, a swimmer's entire view is surrounded by a synthetic image. This environment has two main characteristics to enhance the swimming experience. One of the functions of the pool is to provide underwater entertainment. The user in the pool can enjoy the content displayed on the walls and/or bottom. For example, users can enjoy swimming in beautiful underwater scenery and can interact with aquatic life. Another characteristic is enhanced swimming training. The environment is helpful in improving swimming skills because the pool can show useful information to users, including the user's swimming form or any sensing data in the pool.

We prepared a prototype of the augmented swimming pool. The size of the swimming pool was $3m \times 2m \times 1m$. Acrylic panels with a thickness of $3cm$ were used as the walls of the swimming pool. Each panel was coated with a rear-projection sheet, except for one side that remained uncoated in order to view the inside of the pool. We used six ultra-short throw projectors (RICOH PJ WX4141): three for the side panels and three for the bottom screen. A single Mac Pro with six Thunderbolt display ports was used to generate the images for the projectors. The inside of the pool was coated with circular polarizing sheets.

#### 3.1.1 Underwater Entertainment

In the surround-screen swimming pool, swimmers can enjoy the surrounding scenery as if they were swimming in a real sea with coral reefs. Figure 3 shows the swimming pool displaying a computer-generated scene filled with coral reefs.

Water flow tracing technology enables a user interface for controlling the system and interactions with virtual characters for the underwater entertainment. For example, the user is able to move a computer-generated character by water flow (Figure 4). The user may also change the setting of the system by causing predetermined directions of water flow in the water.

[1]The picture was taken by Greg Goebel. Photo title: False Clown Anemonefish, Scrips Birch Aquarium, La Jolla, California 2012 License: CC BY-SA 2.0 https://flic.kr/p/dLAGyC

**Figure 3: Scenery for underwater entertainment. The bottom and walls of the swimming pool display a computer-generated scene filled with coral reefs.**

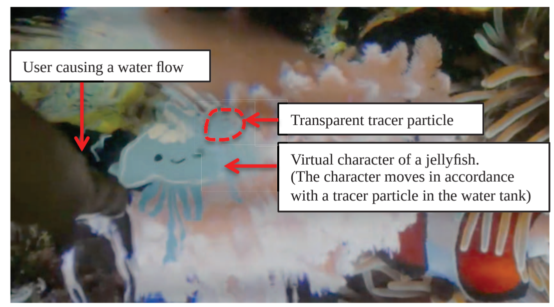



**Figure 4: A user causing a water flow to interact with a virtual character of a jellyfish. The character moves in accordance with a tracer particle in the water tank.[2].**

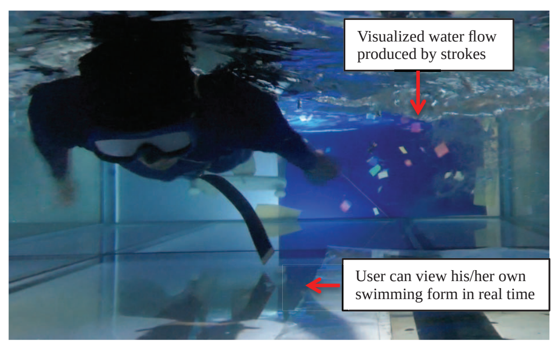



**Figure 5: Enhanced swimming training with visualized water flow. A swimmer's form is displayed on the bottom, and he/she can view his/her own swimming form in real time with the water flow produced by strokes.**

#### 3.1.2 Enhanced Swimming Training

Analyzing one's own swimming form is important in improving swimming skills. However, it is not easy for a swim-

[2]Tsukamoto. http://www.wanpug.com/kitei.html

mer or even a coach to correctly recognize swimming forms. In the augmented swimming pool, the swimmer can view an ideal swimming form and/or his/her swimming form displayed on the bottom and/or walls of the swimming pool. Water flow visualization is helpful for swimming training because the swimmer can visually see the water current caused by his/her strokes in the swimming pool. By comparing the visualized water flow and swimming form with those of a professional swimmer, a swimmer can learn how to swim more efficiently. Figure 5 shows a user swimming, with his own swimming form displayed on the bottom of the pool with visualized water flows.

## 3.2 Transparent Tracer Particles

We prepared two types of transparent particles. One type of particle consists of polystyrene pieces taken from trays widely used for packing foods. Tracer particles made of polystyrene sink in the water and are buoyed by a slight water flow because the specific gravity of polystyrene is close to that of water. The other particles are polyethylene films floating on the water.

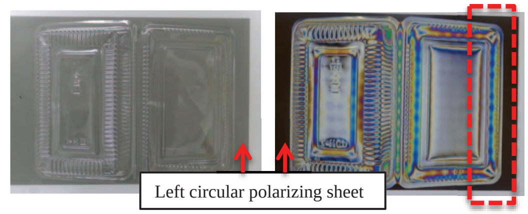
Photoelasticity effects are seen on transparent plastics placed between two polarizing sheets [22, 10]. The effects produce vivid colors in the transparent plastic, as shown in Figure 6. Photoelastic materials exhibit the property of double refraction upon the application of stresses at the time of manufacture. We used some parts of a polystyrene tray as one type of tracer particle to show this vivid color.

Birefringence is an optical property of a material. Birefringence is formally defined as the double refraction of light in transparent materials such as plastic films for wrapping [11]. When the materials are placed between two polarization sheets, the clear materials exhibit vivid colors. Figure 7 shows the setup for viewing the colored plastic films. We prepared a polyethylene film of 0.03-mm thickness and placed it between two linear polarizing sheets on a white backlight. Figure 8 shows the color on the transparent plastic film. The left side of Figure 8 shows the film placed between two linear polarizing sheets with parallel polarization angles, and the right side of Figure 8 shows those with orthogonal polarization angles. The film shows different colors depending on the polarization angles of the polarization sheets. We used the polyethylene films as one type of tracer particle.

## 3.3 Difference between Linear and Circular Polarization

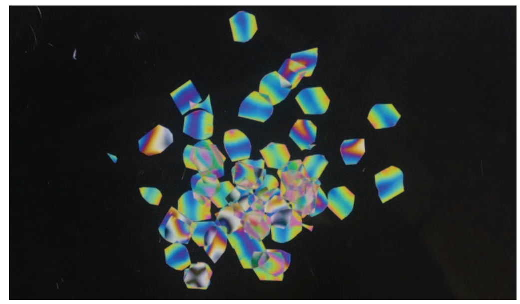
Vivid colors are seen on plastic sheets between two polarization sheets. We used circular polarizing sheets instead of linear polarizing sheets in the pool.

The reason is that the vivid color on plastic sheets disappears at certain angles between two linear polarizing sheets, as shown in Figure 9. However, vivid colors are always seen independent of the angles of plastic sheets between two circular polarizing sheets, as shown in Figure 10. For linear polarizing sheets, the plastic sheet becomes clear at 0° and 90°. On the other hand, the plastic sheet remains colored between two circular polarizing sheets. When tracking the water flow, the tracer particle must always be visible from the camera. Therefore, we used right-handed circular polarizing sheets in the pool and left-handed circular polarizing sheets for the cameras to track tracer particles placed above and/or in the pool.




(a) Polystyrene tray seen without polarizing sheets

(b) Polystyrene tray between a left circular polarizing sheet and a right circular polarizing sheet



(c) Tracer particles made of Polystyrene are placed between left and right circular polarizing sheets. The particles are taken from the place surrounded by a red dot on Polystyrene trays. A White backlight for the display is placed under the sheets to take the picture.

**Figure 6: Photoelasticity effects produce colors in transparent plastics placed between two polarizing sheets.**

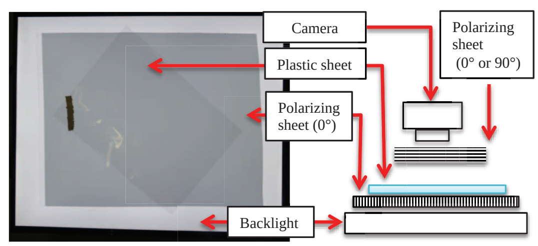



**Figure 7: Setup for showing vivid colors caused by birefringence.**

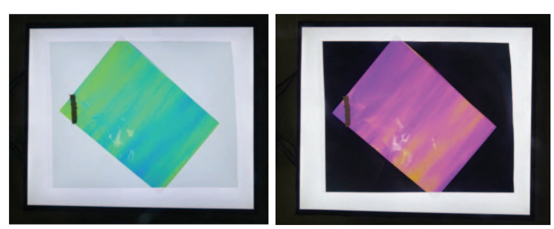


**Figure 8: Polyethylene film placed between two linear polarizing sheets with parallel polarization angles and orthogonal polarization angles.**

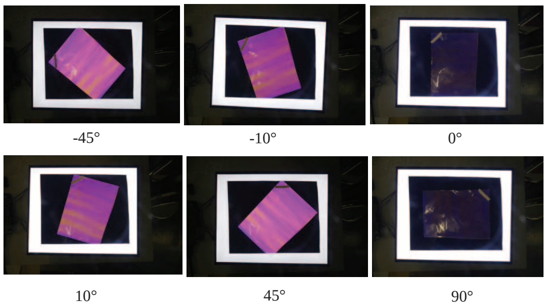



**Figure 9: Colors on a polyethylene film disappear at certain angles for linear polarizing sheets.**

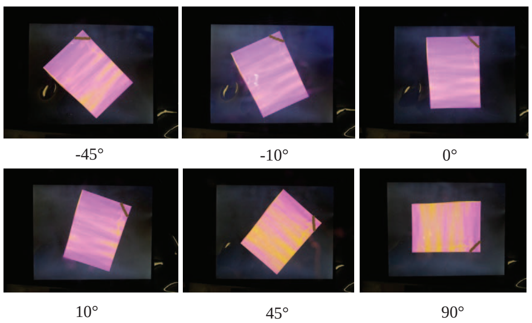



**Figure 10: Colors on polyethylene film are always seem independent of the angles for circular polarizing sheets.**

| Image | Polarizing Sheet | Screen | Tracer Particle |
|---|---|---|---|
| (a) | Without | Visible | Invisible |
| (b) | Left Circular | Invisible | Visible |
| (c) | Right Circular | Visible | Visible |

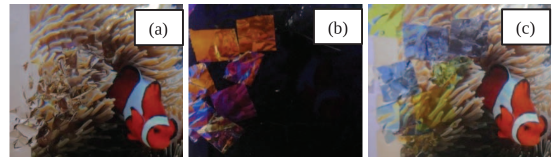
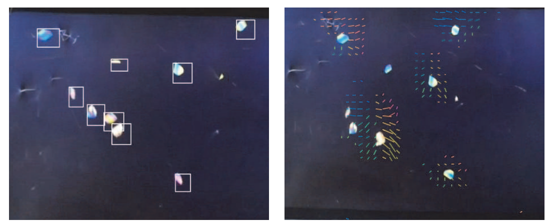



**Figure 11: Relationship of visibility between types of polarizing sheets as seen by a camera, screens, and tracer particles when the screen is coated with right-handed circular polarization sheets.**



(a) Result of blob detection

(b) Result of optical flow

**Figure 12: Tracer particles are traceable by using simple image processing such as blob detection and optical flow.**

## 3.4 Difference between Left- and Right-Handed Circular Polarization

Figure 11 shows tracer particles in a water tank coated with a right-handed circular polarizing sheet, without polarizing sheets, through a left-hand circular polarizing sheet, and with a right-handed circular polarizing sheet.

The situation shown in Figure 11 (a) provides a clear view of screens to users. The situation in Figure 11 (b) enables the stable tracking of tracer particles because bright tracer particles on a simple background are ideal for tracking objects. The inside of the pool is coated with right-handed circular polarizing sheets. Right-handed circularly polarized lights are shielded by left-handed circular polarizing sheets. In brief, the projected images seem dark if we mount a left-handed circular polarization sheet on the lens of a camera. This configuration enables stable water flow tracing in environments with complex backgrounds.

Both the screen and the tracer particles are visible in the situation of Figure 11 (c). The colors of the tracer particles become complementary colors when we change the circular polarizing sheet from left-handed to right-handed. By wearing goggles when using right-handed circular polarizing sheets, users can directly view visualized water flows and images on the screen simultaneously. The colors of the tracer particles become complementary colors when we change the circular polarizing sheet from left-handed to right-handed.

## 3.5 Tracing Method

To track the tracer particles floating in or on the water, we can use image processing such as optical flow and blob detection [8]. Figure 12 (a) and (b) show the results of tracking blob detection and optical flow, respectively. Tracer particles made of polystyrene move in accordance with the water flows in the water tank. As backlights, we used a display showing a white image. Tracer particles are recognized as blobs and are traceable by using blob detection technology. We used a blob detection processing library for the test. The threshold value of luminosity was 0.5, which is the default value. The optical flow can visualize the water flow by tracing the movement of tracer particles floating in the water. To test the optical flow approach, we used code for the optical flow that was uploaded at openprocessing.com by Sid Gabriel Hubbard.

We have to correct for the pincushion distortion when using a flat-shaped underwater housing for a camera to track the particles in the water. Pincushion distortion is an effect in the water that causes images to become pinched at the center. This distortion is seen in images taken in the water because of the differences in the refractive index between air and water [28]. A dome-shaped lens can correct the pincushion distortion optically [3]. Image-processing-based camera calibration [18] is also valid for this purpose.

## 3.6 Dependence on Background Images

Figure 13 shows the changes in brightness depending on the color of the backlight. Figure 13 (a) shows the color of a tracer particle on a white backlight. The color is orange with a white background, which indicates the film will pass through light with a wavelength of approximately 400 $nm$ more than other colors. In other words, the tracing particle reduces the brightness with a blue backlight because blue is the complementary color of orange. Figure 13 (b) shows the same tracing particle with a blue background. The brightness is significantly reduced in this case. However, the brightness increases with a red background, as shown in Figure 13 (b) because the wavelength is close to that of orange.

Distorting the particles or using particles with the photoelasticity effect can reduce the loss of traceable particles. Figure 14 shows a distorted tracing particle floating in a water tank with various colors of backlight. Figure 14 (a) shows the film in front of a white backlight. With the distortion on the film, other colors in addition to orange are seen on the tracer particle. This indicates the tracer particle is visible on a background with more colors. This enables the tracing of water flow in complex scenes displayed on the screen in the pool. As shown in Figure 14 (b) and (c), different parts of the tracer particle are bright on the blue and red backgrounds.

The color changes in accordance with the distance that the polarized lights pass in the plastic. For example, our polyethylene sheet of 0.03 mm thickness shows orange color with a white background. If the thickness is approximately 0.06 mm or 0.12 mm, the sheet shows yellow and green, respectively. This change in color occurs when the sheet is slanted in the horizontal direction, because the polarized lights pass more in the plastic in this case. For this reason, the distorted sheet shows multiple colors.

## 3.7 Differences by Material

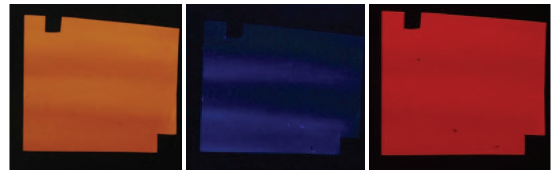
The characteristics of the tracer particles greatly depend on their material. Therefore, we describe several factors affecting water flow visualization and tracking in this section. We prepared two types of tracer particles in this study. Distorted polyethylene films float on the water, and polystyrene films sink in the water. Both tracer particles easily sink and float in the water with a little water flow. By combining these tracer particles, we can visualize water flow on the surface of the water, and in the water near the bottom.

### *3.7.1 Transparency*

The transparency of tracer particles in the water depends on their material. The refractive index of water is 1.33. If the refractive index of the material is close to the water, the material is more transparent in the water (Figure 15). A tracing particle is visible on the surface of the water, but becomes mostly invisible in the water. This transparency also depends on the angles of the tracing particle in the water because the surface sometimes reflects the light from the background at certain angles, and the particle becomes visible at that time.

### *3.7.2 Flotation*

Several types of plastic can float on the water surface. For example, tracer particles made of polyethylene float on the water surface, yet sink into the water easily by the stroke of a user in the swimming pool. The flotation depends on the



(a) White backlight (b) Blue backlight (c) Red backlight

**Figure 13: Change in brightness depending on color of background image.**

(a) White backlight (b) Blue backlight (c) Red backlight

**Figure 14: Distortion on the film produces other colors in addition to the default color on the tracer particle. This enables the tracer particle to be traceable in more colors of background images.**

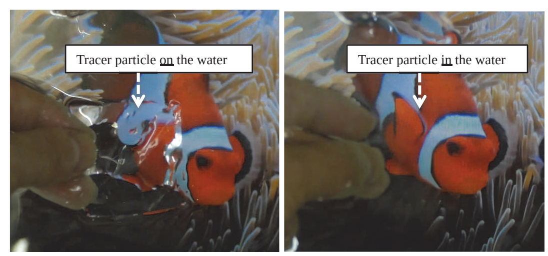



**Figure 15: Transparency of a tracer particle in the water and on the water.**

specific gravity of the material. The specific gravity of water is 1.00, and polyethylene is approximately 0.95. This means pure polyethylene floats on the water. The specific gravity of polystyrene is approximately 1.04, which indicates that it sinks in water. The tracer particles are buoyed by the water currents in the swimming pool.

### *3.7.3 Durability to Water*

We conducted a test to check the durability in water. As a result, some plastics changed color and transparency after an hour in the water. While polyethylene and polystyrene retained their transparency, films made of oriented polypropylene quickly became whiter in the water.

## 4. EVALUATION

We evaluated the stability of water flow tracking technology by using transparent tracer particles in the water with various types of background. Tracer particles having photoelasticity effects were traceable with most of the backgrounds, including underwater video. However, the technology was not available with a dark background that had a scene of the universe.

We also conducted a feasibility test of water flow visualization for swimming training. Tracer particles made of polyethylene floating on the water were able to visualize the movement of the water near the water surface. Moreover, tracer particles made of polystyrene were able to visualize the water flow in the water near the bottom. However, the water flow in the middle of the water layer was barely seen by the tracer particles. To visualize water currents caused by strokes in the middle of the water via breaststrokes, more investigation into materials for tracer particles is required.

## 4.1 Stability Test of Water Flow Tracing

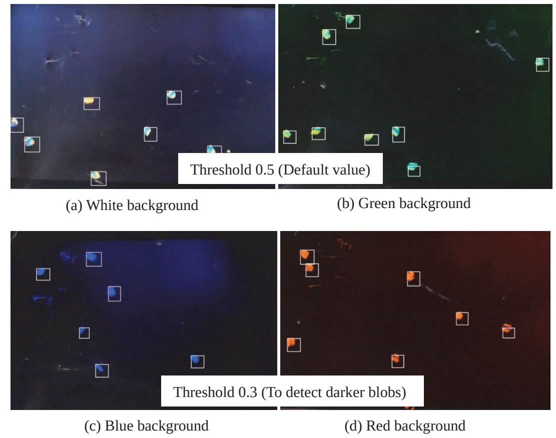
### 4.1.1 *Experiment environment*

We used a library named blobdetection for processing to trace the particles. We also limited the size of the detected blobs to around the size of the tracer particles. We distributed 10 pieces of tracing particles in a water tank filled with water to a depth of 5 cm. We put the water tank in front of a display. The screen was coated with a right-handed circular polarizing sheet on the screen to make the lights from the screen right-circularly polarized. A camera coated with a left-handed circular polarizing sheet was installed above the water tank to track the movement of the particles. We used a USB camera that snaps 30 images per second, and the field of view was limited so the camera only captured the inside of the water tank. We caused water flows in the water tank by moving a plate from the back (far) to the front (near). Two vortexes in opposite rotation to each other were observed on the left and right sides of the tank.

### 4.1.2 *Results*

Figure 16 shows the results of blob detection for tracer particles made of polystyrene with simple color backgrounds. Figure 16 (a), (b), (c), and (d) show the results with white, green, blue, and red backgrounds, respectively. We found that with the white and green backgrounds, the water flow tracings were stable and there were no misdetections throughout the test. However, with the blue and red backgrounds, the tracer particles become darker, and we had to adjust the threshold for luminosity. We found that the detection rate depends on the angles of the particles. When the flat surface of the tracer particle is close to horizontal orientation of the camera, the tracking system can track the particle. However, when the angle of a particle is close to a right angle, the tracking system loses the particles. The angles of the particles continued to change in the vortex. The tracking system was able to measure the direction and speed of the water flow even though the tracing particles sometimes became untraceable.

Figure 17 shows the results with underwater scenery. The tracer particles are traceable in most parts of the background, but become less traceable in the darker parts of the scene. This issue occurred with the background having an image of the universe, as shown in Figure 18. For this background, we were unable to trace the movement of particles using any threshold value for luminosity. When the value was adjusted to find darker blobs, our setup started detecting bubbles as tracer particles. Distorted tracer particles made of polyethylene film also showed similar characteristics to the particles made of polystyrene with photoelasticity effects.




(a) White background (b) Green background

(c) Blue background (d) Red background

**Figure 16: Results of blob detection for tracer particles having photoelasticity on single-color backgrounds.**

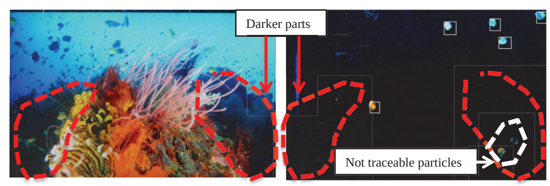



**Figure 17: Tracer particles on a complex background showing an underwater scene. The tracer particles are recognizable, but darker places in the background reduced the traceability. [3].**

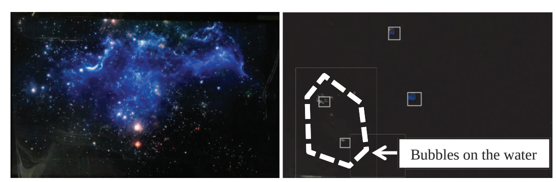



**Figure 18: Tracer particles on a dark background showing a universe scene. The tracer particles are not functional in front of a dark background. [4].**

## 4.2 Feasibility Test for Enhanced Swimming Training

In this test, we asked two swimmers to swim in a swimming pool filled with tracing particles. One of the testers was a trained swimmer with more than 10 years of experience, and the other was an amateur swimmer. Figure 19

[3] Image taken by John Smith. Photo title: Universe License: CC BY-SA 2.0 https://www.flickr.com/photos/94908112@N07/8645017104

[4] Image taken by Tetsuji Sakakibara. Photo title: 141231-2_South Emma Reaf #2_6 License: CC BY-SA 2.0 https://www.flickr.com/photos/tetsuji0105/16435879016

shows the test environment. More than 1,000 pieces of tracer particles made of polyethylene were scattered in the swimming pool. We put right-handed circular polarizing sheets on the bottom of the swimming pool. The swimming pool displayed a video of a swimmer on the bottom with a white background. To sustain the position of the user in the pool even after strokes, we asked the users to wear harnesses and to fix the edge of the harness at a place outside of the pool, as shown in Figure 20. Users swam in the swimming pool using two types of swimming styles: breaststroke and freestyle. We found that the water flow generated near the water surface was visualized by the stroke. However, with the floating tracer particles, visualizing the water flow produced at the middle and bottom of the swimming pool by the breaststroke was not efficient. The reason is that only a few particles sank in the water based on the swimming style. Tracer particles made of polystyrene sunk in the water. Therefore, the particles could move in the swimming pool in accordance with water flows caused by strokes.

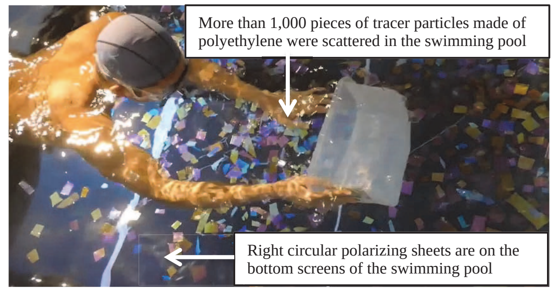



**Figure 19: Surround-screen swimming pool filled with tracer particles.**

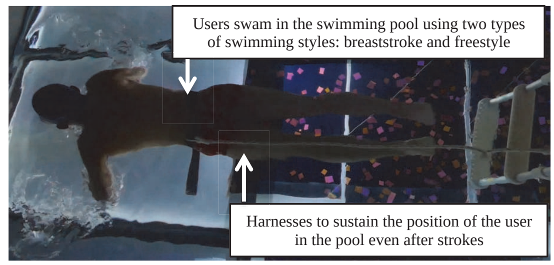



**Figure 20: Feasibility test using tracer particles for swimming training.**

## 5. LIMITATIONS

The transparent tracer particles have a flat shape. The shape results in three issues. First, the tracking system sometimes loses the visualized particles when they are vertical because they look very thin in front of the camera for tracking. Second, flat tracer particles become recognizable when they reflect light from the background. In addition, the particles tend to stick to the body of the swimmer, and thus may reduce the swimming experience.

Ball-shaped tracer particles should solve these issues. Water-absorptive polymers used for growing plants are shaped balls that become quite transparent in water without requiring reflection. With some stress on the surface, the plastic also shows the characteristic of photoelasticity. We suspect that ball-shaped tracer particles made of water-absorptive polymers can solve these issues.

To visualize the water flows caused by strokes, the tracing particles need to be in the middle of the water. We also have to invent materials that have a specific gravity closer to that of the water.

Preparing a surround-screen swimming pool is quite expensive and time-consuming. For swimming training with visualized water flow, we can put reflective plates as mirrors around the swimming pool. By emitting white light through a polarizing sheet to the plates in the pool, people wearing goggles coated with polarizing sheets can view the vivid colors of the tracer particles. A reflective object can maintain its polarization property when the lights are reflected. This enables the same situation as tracer particles placed between two polarizing sheets.

Users might accidentally swallow the tracer particles in the water when they breathe. Therefore, wearing a face mask for swimming is advisable for the method. To avoid mechanical issues in the water circulation system of the swimming pool, placing sponges in the inlet port is recommended.

## 6. CONCLUSION

We introduced a surround-screen swimming pool filled with transparent tracer particles for water flow visualization. The particles enable interactions in underwater entertainment by tracing the water flow by a camera. Moreover, for swimming training, users can view their swimming form displayed on the bottom via visualized water flows caused by strokes in the swimming pool.

According to our test for checking the stability of water flow tracing, the tracer particles enable stable tracing even with complex backgrounds. However, the traceability decreased significantly with darker backgrounds. We found that water flow visualization caused by a swimmer's strokes is also possible from the feasibility test. Nevertheless, the visualization of water movement in the middle of a swimming pool was not efficient because the tracer particles tended to float on the surface of the water or sink to the bottom. Further research on how to sustain the positions of tracer particles in the middle of the water is required for swimming training support.

We used flat-shaped tracer particles in this research. However, the shape of transparent tracer particles becomes visible in the water depending on their angles because of reflection. In addition, the particles always change their width and height in the images because of their shape. This situation makes stable tracing difficult when using a camera. As a solution, we are planning to use ball-shaped tracer particles with birefringence.

The reflective index of plastics such as polyethylene and polystyrene are closer to that of water than air, but are nevertheless different. For this reason, the particles are not completely invisible to the user. We can use water-absorptive polymers as tracer particles to solve the issue. The material becomes invisible when placed in the water, and changes its polarization property when using two polarization sheets.

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