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# Water Flow Measurement Technology Assessing Spatial User Interaction in an Underwater Immersive Virtual Reality Environment


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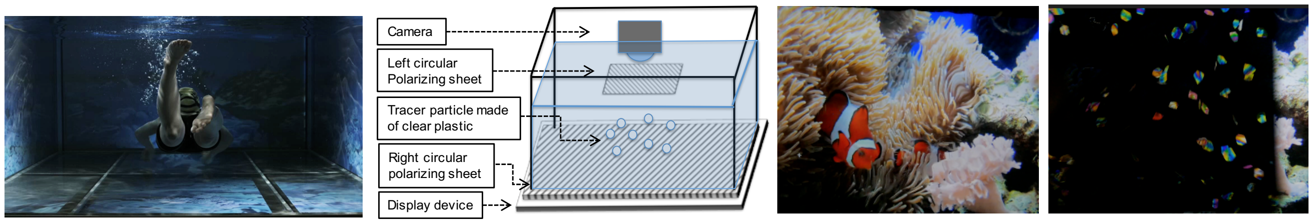


(A) Surround-screen swimming pool providing a swimmer with an immersive virtual reality experience.

(B) Setup for proposed water flow tracing technology. Cameras track the movement of tracer particles distributed in a swimming pool.

(C) Transparent tracer particles become invisible in water. Users can view displayed images through the particles.

(D) Visualized tracer particles. We employ a polarization-based method to realize the tracking of transparent particles.

Figure 1: A novel water flow measurement technology using transparent tracer particles. This technology realizes underwater spatial user interaction in an underwater immersive virtual reality environment (A). The tracer particles become invisible in water. Therefore, tracer particles do not stop users from viewing the content on the screen (B, C). Cameras cannot track tracer particles if they are invisible. Accordingly, this demonstration presents an optical solution with which polarization-based technologies are employed to resolve the technical problem (D).


## Abstract

Underwater immersive virtual reality (VR) environments can reproduce unique VR experiences such as swimming in the sea with beautiful coral reefs and a cage surrounded by sharks. Underwater VR poses new technical challenges to creating user interactions because water and the surround-screen make existing methods for realizing user interaction irrelevant. In this research, we present a potential water flow measurement technology aimed at accessing human-computer interaction in underwater VR. Flow measurement can be realized by using tracer particles that are scattered in fluids. However, existing tracer particles are not suitable for underwater immersive VR because the particles stop users from viewing the content on the screen. Therefore, we propose transparent tracer particles that become invisible in water and polarization-based technologies that enable cameras to track the movement of particles. This technology enables virtual objects in VR to react with the actual movement of water and haptic feedback by creating water flow in the swimming pool. These additions would enhance the illusion of immersion in underwater VR.



**Index Terms:** Human-centered computing—Interface design prototyping; Human-centered computing—Virtual reality


## 1 Introduction

We propose a novel water flow measurement technology that realizes an underwater spatial user interaction in a surround-screen swimming pool. The swimming pool provides an immersive virtual reality (VR) experience to the swimmers (Figure 1 (A)) [2]. Underwater VR can reproduce swimming experiences such as a sea with beautiful coral reefs and a cage surrounded by sharks [7, 11].

This configuration of underwater VR poses new technical challenges, which have not been addressed by previous studies. User interfaces such as gaming controllers and motion capture systems enhance the immersion in VR by creating interaction between users and the virtual environment. However, the surround screen and water make existing methods for realizing user interactions irrelevant. For example, position tracking systems using infrared (IR) are widely used for enabling interactions in standard immersive VR environments on the ground [5, 6]. However, existing position-tracking devices are difficult or impossible to use in a surround-screen swimming pool because of the optical distortion, reflection, and IR absorption caused by water [1, 10]. In addition, position tracking technology using visible lights is unstable in complex backgrounds displayed on the surround-screen [8]. In this research, we present a potential water flow measurement technology aimed at accessing human-computer interaction in underwater VR environments.

Tracer particles scattered in fluids are used for fluid measurements [4]. Cameras track the particles in the fluid moving along the flow. To enable cameras to track the movement of the particles, tracer particles must be conspicuous. To render tracer particles especially bright against the background, fluorescent materials are used as tracer particles in many cases. Laser light or parallel light configured by a lens is emitted toward the measurement environment to make the particles glow. However, existing tracer particles are not suitable for underwater immersive VR because fluorescence particles stop users from viewing the content on the screen.

In this research, we propose transparent tracer particles that become invisible in water (Figure 1 (B, C)). The tracer particles are made of fluorine resin. The refractive index of the material is nearly equal to water's; hence, almost no refraction occurs on the surface of the material in water. Therefore, users can view the displayed images throughout the particles. This configuration enabled higher invisibility compared to previous methods [12]. Cameras cannot track tracer particles if they are invisible. Accordingly, this research demonstration presents an optical solution with which polarization-based technologies are employed to resolve the technical problem (Figure 1 (B, D)). The proposed water flow measurement technology requires lights only from screens to visualize tracer particles. This configuration reduces the cost of insulation compared to previous methods using complex optical systems.

## 2 Water Flow Measurement Realizing Spatial User Interaction in Underwater Virtual Reality

### 2.1 System Configuration and Methodology

We propose a potential water flow measurement technology using transparent tracer particles. The tracer particles must be highly transparent so they do not prevent swimmers from viewing the content on the screen in a surround-screen swimming pool. The technical problem is that the cameras cannot view the movement of particles if they are transparent. Therefore, we employ a polarization-based method to realize the tracking of transparent particles. We placed circular polarizing sheets on the inside of the screens and installed circular polarizing sheets in the opposite direction on a camera for tracing. This configuration produces a dark background and bright tracer particles for the camera. This situation is ideal for optical tracking [9]. The dark background is the effect of light shielding caused by circular polarizing sheets. The reason only the particles are bright is that they are made of plastic, which has the optical property of rotating the polarization plane regarding polarized light [3]. Circular polarization is used because the particle becomes dark at certain angles if we use linear polarization.

### 2.2 Application

#### 2.2.1 Spatial User Interaction

VR is a technology that provides users experiences as if they actually were entering the virtual world made of computer graphics. One of the issues in underwater VR is that the immersion is reduced because the virtual world does not produce any reaction supposed to be caused by water flow. For example, if a real object is floating in a swimming pool, it moves with water when a wave or water flow is caused by people in the pool. Underwater plants also change forms when water flow strikes them. Water flow measurements in underwater VR can create proper redactions of the virtual world supposed to be caused by the movement of water.

#### 2.2.2 Haptic Feedback

Previous studies have shown the reproduction of the five senses, such as hearing, smell, and touch, in VR is necessary to increase the immersion. However, the water causes technical issues concerning the reproduction of five senses in the case of underwater immersive VR. For example, the stereophonic sounds created by multiple speakers surrounding users increase the sensation of stereoscopic video. However, sounds travel four times faster in water than in air, and humans cannot recognize from where the sound originates in the water. Some research shows ultrasonic wave and air cannons can reproduce the sensation of touch for VR. Nevertheless, these technologies are unusable in the water. Haptic feedback is the use of the sense of touch in a user interface design. One of the methods to provide haptic feedback is controlling water flows in the environment. Water flow measurements help create proper water flow with a combination of pumps or screws.

### 2.3 Swimming Training

Underwater VR can be used for a swimming training environment, as it can also display information valuable for swimming, such as swimming forms and previous records of the swimmer as a 3D character. Showing swimmers visualized water flow and telling them how to make proper water flow should enhance swimming training systems using underwater VR.

## 3 Demonstration

In the demonstration, we show transparent tracer particles that are invisible in water and the method to make them visible to cameras. Moreover, we show a brief video explaining the underwater immersive VR environment and possible user interactions with the proposed water flow measurement technology. To demonstrate the technology, we have prepared a fish tank made of glass filled with water and proposed tracer particles. We place a monitor coated with a right circular polarizing sheet behind the fish tank. We prepare eyeglasses coated with left circular polarizing sheets so the audience can see the visualized tracer particles physically. Additionally, a camera equipped with a left circular polarizing sheet tracks the movement of tracer particles in the fish tank. The audience can interact with a simple application as virtual characters moving with the water flow displayed in the monitor.

## 4 Conclusion

We proposed a water flow measurement technology using transparent tracer particles scattered in the water. This technology has the potential to realize user interactions in underwater VR. We employ circular polarization to configure an ideal situation for optical tracking with a dark background and bright tracer particles. In the demonstration, we present the water flow measurement technology by using a small fish tank with a monitor coated with a circular polarization sheet. Audiences can see tracer particles being invisible in the water, but visible through eyeglasses coated with circular polarizing sheets.


## 5 Acknowledgement

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