AquaCAVE: Augmented Swimming Environment with Immersive Surround-Screen Virtual Reality

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ABSTRACT
AquaCAVE is a system for enhancing the swimming experience. Although swimming is considered to be one of the best exercises to maintain our health, swimming in a pool is normally monotonous; thus, maintaining its motivation is sometimes difficult. AquaCAVE is a computer-augmented swimming pool with rear-projection acrylic walls that surround a swimmer, providing a CAVE-like immersive stereoscopic projection environment. The swimmer wears goggles with liquid-crystal display (LCD) shutter glasses, and cameras installed in the pool tracks swimmer's head position. Swimmers can be immersed into synthetic scenes such as coral reefs, outer space, or any other computer generated environments. The system can also provide swimming training with projections such as record lines and swimming forms as 3D virtual characters in the 3D space.

Author Keywords
Augmented Sports; Swimming; Immersive Environment; Virtual Reality; Projection-based Systems; CAVE

INTRODUCTION
Swimming is one of the most popular sports, and there are many benefits of swimming for maintaining physical and mental health. On the other hand, maintaining motivation to keep swimming in a swimming pool is sometimes problematic because swimming requires a monotonous repetitive motion for a long time. Unlike swimming in the sea, where swimmers can enjoy the change of scenery, swimmers in a pool can only see the bottom of the pool thus the experience tends to be boring. In addition, learning and improving one's swimming form is not easy, because he/she cannot see his/her swimming form in the water in real time.

AQUACAVE
In this research, we took a new approach in which the walls of a swimming pool are replaced with stereoscopic rear projection panels, like a virtual reality environment with surround rear-projection screens known as CAVE [1]. With this configuration, a swimmer's entire view is surrounded by a synthetic image and the system can display any scene, such as coral reefs and shark cage diving. This environment should also be helpful as a training environment for swimmers, as it can also display information such as swimming forms and record lines. We call this system AquaCAVE (Figure 1).

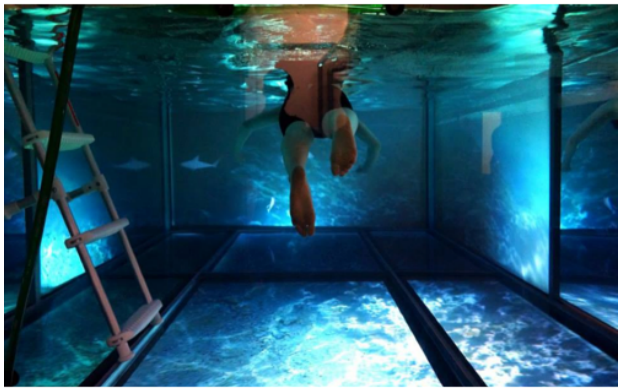

Figure 1. AquaCAVE: immersive environment for swimmers with multiple stereoscopic projections on surrounding acrylic walls

RELATED WORKS
Immersive Terrestrial Scuba Diving Using Virtual Reality [2] is a system that provides an immersive SCUBA diving experience using VR headsets with a motion platform with their outstretched arms and legs placed in a suspended harness. However, providing the sensation of water was difficult since the user is on the ground. One of the contributions of AquaCAVE is the enhancement of swimming experience by providing the realistic swimming sensation in the virtual world. The other contribution is the improvement in the quality of swimming training. One approach is to use an underwater robot that swims together with a swimmer and shows information with an attached underwater display [4]. However, it is still not possible to provide an experience in the actual sea, because the size of the display is limited. Dungeons & swimmers [3] is an interactive game using audio feedbacks to maintain the motivation to swim. However, swimming training like form correction is not feasible without visual feedbacks.

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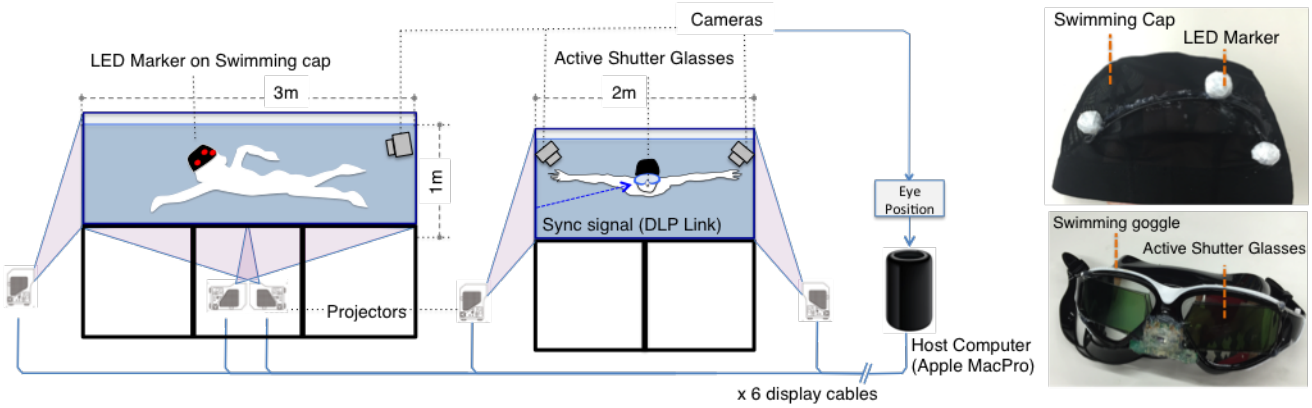

Figure 2. AquaCAVE system configuration

SYSTEM IMPLEMENTATION

The system configuration is shown in Figure 2. The size of the swimming pool used for this research is 3m ×2m ×1m. Each wall is coated with a rear-projection sheet. Six ultra-short throw projectors (RICHO PJ WX4141) are used for CAVE-like projection. Images are provided from a single Mac Pro with six thunderbolt display ports. The swimmer just wears his/her swimming goggles with LCD shutters to see the stereoscopic view, and a swimming cap with visible light LED markers tracked by cameras in the pool. Based on the obtained head position, the view frustum for each projection panel is calculated. Each eye position can be also estimated for the immersive stereoscopic scenes.

We prepared two types of contents to be presented for the initial trial of the system. One was a non-stereoscopic 360-degree spherical video of coral reefs recorded using six GoPro cameras. The captured videos were stitched together to be in equirectangular format. With this projection, a swimmer could feel as if he/she was swimming in that environment. We also created an underwater computer graphics scene to check the feasibility of stereoscopic vision in the water. Another type of content is an ideal swimming form under the swimmer. Motion capture data of a swimmer obtained from a motion capture dataset is used for this purpose.

PILOT STUDY

We asked a highly trained swimmer with ten years experience to swim in the environment. As a result, the limited space could support a realistic swimming experience, because the trained swimmer could stay in the same position. However, for untrained swimmers, staying at the same position was not easy. Moreover, this system still needs to address some water specific issues. For instance, the effect of the optical distortion in the water must be clear, because even slight position changes can make errors in swimming training. In addition, reflection and infrared radiation absorption affect the tracking accuracy. We first tried a combination of an infrared light LED marker and a pair of cameras. However, infrared light decays greatly in the water, the recognizable distance between cameras and an LED was about 40cm. Thus, we used visible light LED. Since this system projects complicated images, accurate head tracking should be difficult depending on the scene.

CONCLUTION AND FUTURE WORK

We introduced AquaCAVE, a system for enhancing swimming experience. Using a combination of CAVE-like projection-based virtual reality with a swimming pool, swimmers can be immersed into synthetic scenes. The system can be also used for swimming training with projections such as record lines or swimming forms.

From some pilot studies, we noticed that AquaCAVE still needs to address some problems regarding the limited size of the pool and water characteristics. One possbile solution is to attach water pumps to create a water current in the pool. The water flow would be able to control the position of the swimming user and give him/her an appropriate feedback in accordance with the scene projected. Pincushion distortion in the water should be removed by a proper camera calibration, but further study of filtering methods for visible light head tracking in the CAVE-like environment is required.

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