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# Architecture of the virtual training system for buoyancy control

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**Abstract**

*In this paper we present the structure of the simulator which would allow diving beginners to experience the effect of buoyancy control mechanisms before actually entering the water. We believe such training would be less stressful and safer for all participants, but it should also reduce the time in water needed to manage basic practical diving skills. Central design requirements for the system were: realistic modelling of diving physics, various options of man-machine interface and possibility of immersion. With future studies we plan to clarify to what extent the immersive VR interfaces are able to further improve the diving training experience.*

Categories and Subject Descriptors (according to ACM CCS): I.3.7, I.6

## 1. Introduction

Scuba diving is a popular and attractive both leisure time and professional activity [1]. Once mastered, it is a relaxing and enjoyable activity, if practised within specified safety margins - limitations in depth and time. Education and training of divers is therefore for safe and accident-free diving. But no matter how elaborate programs for certification of divers might be, there is still an essential gap among their theoretical and practical part. This gap is most evident in the introductory courses, when novice is facing the use of scuba gear for the first couple of times. This may cause panic or at least inability to calmly asses the situation and act as taught in theoretical classes. Our virtual training system aims to overcome such situation with better preparation before the first exercises in the water.

**Buoyancy control** Establishing and maintaining neutral buoyancy at any depth is the most difficult skill for majority of novices, taking also most of the time during initial practical training. Diver can control his own buoyancy by emptying and filling the two volumes with air from the air tank. The first volume are his/her lounges and the second one is a hollow jacket (Buoyancy Control Device, BCD), which can be filled and emptied using two buttons on the handle, called inflator. To start a dive, air is first released from BCD to achieve negative buoyancy. While going deeper the speed of descent increases and BCD needs to be filled with air again to reduce it. The process is reversed on moving up. With our simulator a novice will be able to develop control of this mechanism in the safe, dry environment.

## 2. System architecture

**Background** While planning the requirements and goals of the virtual buoyancy control (VBC) training simulator, we were trying to adopt the following principles of the human-centered design (HCD). Based on this principles and the opinion, that "...desktop VR (keyboard, mouse and screen) and basic forms of video-projected VR deliver sufficient interactivity for up to 85% of i3D/VR applications..."[2], we set the following requirements for our VBC system: (a) Realistic physical model of diving. (b) System should be useful in several configurations. (c) All input interfaces should be modular and independent of the physical model. Various options for detection of breathing will be tested. (d) Full immersion using HMD and motion tracking will be considered as an option. (e) Training tasks should correspond to realistic depth maintenance exercises in the water. Estimation of achieved performance should be possible.

**System components** The system consists of (a) the mathematical model of the standard two air-chamber (lounge and buoyancy control device) diving system; (b) 3D visualisation incl. basic user interface; (c) the subsystem for detection of the breathing phases; and (d) optional VR navigation and immersive visualisation components. The user interface has the two main modes: (a) the standard GUI incl. menus and dialogs for initial system setup and post-training evaluation (upper part of the figure); and (b) training interface incl. full-screen 3D visualisation, subsystem for detection (or simulation) of breathing, inflator interface and optional equipment for immersive display and navigation. To implement the system we have used C++ language and the Cortona SDK [3] for VRML.

**Physical model** We take into account the physical laws of diving, based on Newton's and Boyle's law. The change of the air volume in the diver's lungs due to breathing is considered; but we neglect the change in the thickness of the diver's suit due to the change of hydrostatic pressure. We also suppose the temperature of water to be constant.

**Visualisation and basic interface** Our VE is a swimming pool, the viewpoint during training is a view of a diver. Fixed in the viewpoint are two kinds of virtual instruments: (a) true diving instruments - depth meter and pressure gauge; and (b, optional) training instruments - timers and training task description. For estimation of depth, orientation and vertical speed, air bubbles from the regulator and inflator are an important element of the visualisation. For more realistic 3D representation, our system includes amplified respiratory sounds, sounds from BCD inflation/deflation, air bubbles, touching of the ground and finally, (optional) synthetic sounds for beginning/end of the training phases.

**Input interface subsystems** In the full-featured training session the user will interacts with the system using two main interfaces (inflator and breathing measurement system), that need some sort of hardware devices for efficient implementation. For the inflator, we use a joystick (which is similar in shape) or, if it is not present, air transmission can be controlled with the virtual 3D objects on which virtual buttons are activated by mouse. If a device for detection and measurement of breathing is not available, controls (3D sliders) for adjusting the parameters of the breathing simulation are also present.

**Breathing subsystem** Omitting breathing from our training would be a serious drawback as it is the the essential mechanism in controlling buoyancy. Basically, the value of one single parameter - current point in the breathing cycle, which corresponds to the volume of air in the lounges - has to be available at each moment in time. We may (a) use a measuring device, which would allow estimatation of the breathing phase or (b) simulate breathing. Devices available for measurement are by no mean cheap or widely accessible. Several options exists, from measurement with pneumotachograph, measurement of sound signals from different positions on the chest to measurement of the chest and abdomen circumference, however our current development development is focused toward implementing acoustic airflow estimation and estimation using simple pressure transducer.

**VR navigation and interfaces** In system requirements we defined the role of immersive technology as optional. At present the following two configuration of devices are supported: (1) integrated helmet with low-res stereo display and 3-DOF (orientation) tracker, and (2) mono hi-res HMD, and 4-point 6-DOF electromagnetic tracker. Currently the first configuration seems to provide the best price/performance ratio for the given application, but more detailed comparison will be done later when the system will be tested under realistic circumstances.

Other optional devices which should improve the realism of the training are related to the described input interfaces: (a) inflator handle with built in gyroscopic switch (to be active in upright position only) and two buttons to control the volume of air in the BCD; and (b) any measurement devices for detection of the breathing phases.

**Training Tasks** The VBC training task is as an ordered sequence of $i$ pairs (depth $h_i$, time $t_i$). Training session is an attempt to perform a training task within the set of system limitations (speed of ascent, descent, speed at touchdown, available air, tolerance of depth variation, etc..). Training sessions are logged, performance criteria are time between depths, depth deviations, used air and speeds within limits.

## 3. Conclusion

We described the motivation, goals and architecture of the virtual reality training system for novice divers. The main skill to be obtained using this simulator is buoyancy control - ability to move under water vertically from one depth to another and maintain steady position there. Basic configuration of our modular system runs on a standard computer without specific VR hardware. Several options have been proposed in this architecture for detection of the breathing phases. Development of the full system has not yet been completed.

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