Virtual Reality Games in Sensory Deprivation Tanks

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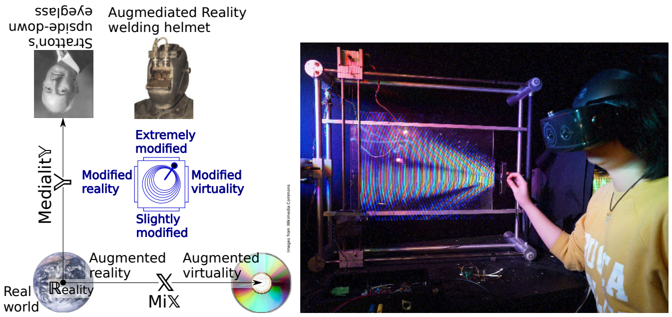

Fig. 1. Left: Mixed (X) Reality and Mediated (XY) Reality address a continuum in which reality is at one extreme, i.e. the *origin* of the *X-Reality axis* and the *Y-Reality axis*. Right: The "Mix" continuum fails to capture sensory attenuation technologies like theaters or darkrooms where a phenomenological augmented reality lock-in amplifier and abakographic robot [1] allows us to photograph and visualize (in 3D) sound waves. We have proposed, therefore, XYZ Reality or A-Z-Reality™ (abbreviated ZR™ or ZReality™) which is multidimensional, multiscale, multimodal, and multidisciplinary.

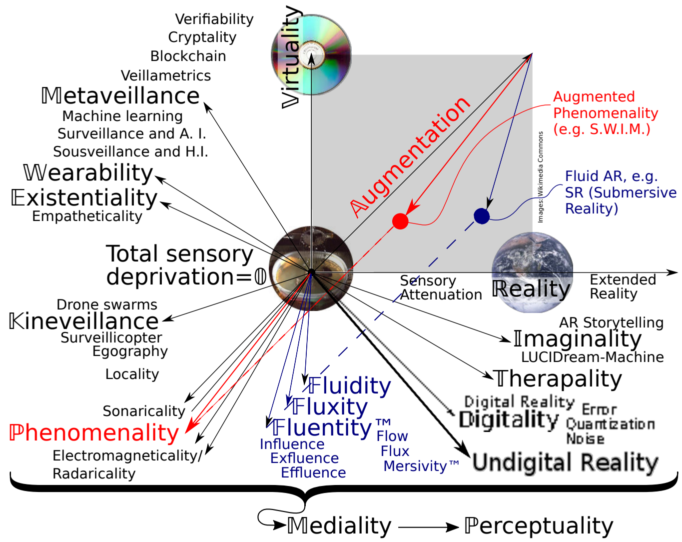

Fig. 2. In the Multimediated Reality Continuum [2], the space is multidimensional and nothingness (zero stimulus, i.e. total sensory deprivation) is at the origin. Augmented Reality consists of a combination of Reality and Virtuality. In this paper we focus also on the axes of Phenomenality (e.g. otherwise invisible but real world phenomena like sound waves made visible through phenomenological augmented reality), and Fluidity in an immersive and submservive augmented reality space. Overall, the proposed gaming experience extends beyond the Virtuality/Reality continuum in Fig. 1.

Abstract*—We present a new form of game-playing that takes place among one or more participants, each in a sensory deprivation tank, wearing a waterproof VR headset, for biofeedback-based virtual interaction. Whereas conventional VR (Virtual Reality), AR (Augmented Reality), and Mediated ("XY") reality include an axis that spans from reality to virtuality (i.e. with reality as the origin), we build upon the newer multidimensional framework of *multimediated reality* that has nothingness at the origin (i.e. as facilitated by total sensory deprivation). This sets the stage for a novel class of games that facilitate the suspension of disbelief for the game's players. Floating in the tank creates a new context for a heightened sense of imaginality in the world of immersive/submersive reality. Specifically, our game involves mediation while singing a steady note, using phenomenologically augmented reality (e.g. seeing sound waves with an augmented reality lock-in amplifier). A VR game that uses the binaural beat brain entrainment technique in computer-mediated/networked sensory deprivation tanks is developed.

I. Theaters and Darkrooms; Sensory Attenuation

Sensory attenuation is an important element of VR and other Realities. We often deliberately attenuate senses, and sometimes accidental sensory attenuation occurs, which may help or hinder, e.g. to help us see better through sensory attenuation, or sometimes, unfortunately, we have accidents and even death occur due to VR, so we must be careful!

Examples of deliberate sensory attenuation are the blinders placed on horses, or a ball cap used by humans, to block out extraneous vision such as light falling from above onto the eyes. Sports players also use black makeup to improve their vision by attenuating stray light, as shown in Fig. 3.

Fig. 3. **Deliberate sensory attenuation** has a long history. From blinders on horses, to ball caps on humans, to simple use of makeup to attenuate light and focus our attention better.... Here, Stephanie, Age 12, returns from a school sports "Games Day" wearing vision-enhancing makeup. In some sense this kind of makeup has become a symbol for the celebration of sport.

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Theaters are large darkrooms with controlled lighting to mediate an audience's perception of visual input, guiding their attention to the main screen or actors. Extraneous vision (chairs in the theater, other audience members, etc.) is diminished with darkness, while desired content (e.g. the screen or actors) is augmented with lights.

Sensory deprivation can go beyond the theater or darkroom. Other senses can also be diminished (e.g. touch, smell, hearing, and gravity). Sensory attenuation has a long history, dating back to sleep masks that attenuate vision. Sensory deprivation is also used in alternative medicine [3].

II. Multimediated Reality

As with theater, people wear VR (Virtual Reality) headsets to enter into a controlled environment. In fact, the first use of the term ”Virtual Reality” was in theater [4].

For more than 20 years, researchers treated reality and virtuality as two extremes along the Reality-Virtuality (Mixed-Reality) continuum [5]. That same year (1994), a different Reality-based framework was introduced by Mann in which he added a second dimension named Mediality, as shown in Figure 1 [6], [7]. In both frameworks, the origin was set to be unmodified Reality. However, neither Milgram's nor Mann's continuum directly include sensory attenuation technologies like sunglasses and ear plugs. A more comprehensive multi-dimensional framework, *Multimediated Reality*, was proposed to encompass all sensory mediation (augmentation or attenuation) technologies [2], as shown in Figure 2. Instead of having unmodified Reality as the origin, the origin of Multimediated Reality is nothingness (“Total Sensory Deprivation = 0”), and multiple axes including Virtuality, Phenomenality, Digitality, etc. originate from that point.

One active research area in VR is exploring how to create more believable (immersive) virtual environments [8][9]. But since humans are very familiar with the reality they live in, any small misalignment with reality is very noticeable and causes the body to react (e.g. nausea, motion sickness) [10]. However, attenuating reality in mediation, as shown in Figure 2 gives us the option to introduce desired sensory stimulations while isolating undesirable stimulations. People tend to perceive any information as reality (even hallucinations) when put in a sensory deprivation tank, for example [2]. Accordingly, we propose VR games in which each player is in a sensory deprivation tank.

III. Games, Entertainment, and Media

We propose the use of this new medium of artistic expression as the basis for a number of games we call “veillance games” and “metaveillance games”. In one example game, we have a microphone displaying its metaveillance wave function, and invite people to sing into the microphone and see the effect on its wavefunction. In particular, this game gets interesting when we use multiple microphones nearby or remotely, so that when one person sings, others are invited to match the exact phase of that person's voice. Each new player that joins is invited to exactly match the phase of all the other players already on the network. Using the power of phase-coherent detection (i.e. the lock-in amplifier), we created a shared virtual reality environment in which a number of participants can sing together in one or more locations, and try to match the phase of a steady tone (e.g. match each other, or match a recording of past participants if there is only one player), and see who can produce the most pure tone. Additionally, we can set the tone quite high, and, using the SYSUxMannLab Lock-in-Amplifier (the world's only lock-in amplifier that can aggregate multiple harmonics [11]) we created a competition game for throat singers to hit multiple harmonics (while deliberately missing the fundamental) simultaneously.

Singing a little too high, the phase advances forward, and the waves radiate inwards toward the sound source, in the virtual world.

Singing a little too low, participants see the waves retreat outwards from the source.

The goal of the game is to stabilize and lock-on to the wave and make it “sit” still. The visuals for the game build on what has been referred to as a “sitting wave” [1] and is distinct from the concept of a *standing wave* [12].

So in summary, the object of the game is to generate “sitting waves” by singing.

We found this process to be very meditative, and as a form of meditation, to be quite engaging. To take it a step further, we created a series of sensory deprivation chambers (soundproof anechoic chambers in darkrooms). Each chamber was fitted with a sensory deprivation tank, thus allowing for a fully immersive VR experience.

Each player is isolated from external sensation, other than the game, which itself is collaborative. Thus we have communal sensory deprivation as a new form of immersive VR.

To visualize the soundwaves, we have above each sensory deprivation tank, suspended a robotic mechanism to trace out the sound waves. The sound waves are traced in a sound-evolving Argand plane, i.e. in the 2 dimensions the Argand plane (one dimension for real, and another for imaginary), and in the third dimension is time. Thus a pure tone appears as a helix in the 3D space.

See Fig. 4 for experimental setup. Various nodes were setup around the world, over the Internet, so that participants in Toronto, Silicon Valley, and Shenzhen, China, could link together and mediate using biofeedback from within sensory reprivation tanks. See Fig. 6, Fig. 5, and Fig. 7.

A. *Mersion™ and Mersive™ User-Interfaces*

The concept of underwater or in-water interactive multimedia experiences and virtual reality was first explored by Mann et al. as “Immersive Multimedia”, “(Im/Sub)mersive Reality” and “Immersive (direct) Experience” [13], [14], [15], [16], [17], [18], [19], [2], and further developed as a form of underwater meditation using other forms of underwater multimedia including 3D graphics, vision, and underwater brain-computer interfaces [15], [2], as illustrated in Fig. 8.

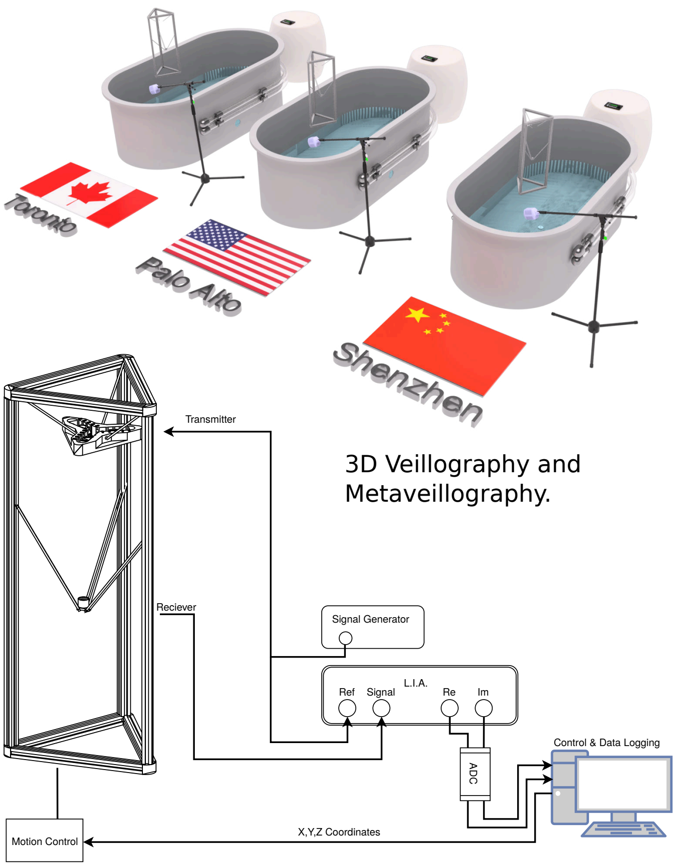

Fig. 4. Setup for sensory deprivation tank singing+meditation game/performance. Sensory Reprivation™ Tanks: players are distributed across the world but play together in real-time. The game involves singing and holding a steady pure note. Each tank serves to isolate the players from their sensations of any other *reality*, while allowing for a surreal communal bathing experience linked by their sound waves (seen and heard), allowing the game to exercise deeper control over the players' experiences. Microphones and speakers allow players to interact with (hear and watch, and contribute to) a game's audio soundfield generated by other players. Players engage with an audio-visual feedback system, while meditating in the sensory reprivation tanks. Above each tank there is a robotic sound visualizer similar to that shown in Fig. 1 (right). A number of sensory deprivation tanks are networked so that multiple players can compete worldwide. Each player interacts with a SWIM based on the Delta configuration of 3D positioning device.

B. Indirectly Immersive Reality

The Mannfloat™ fitness game is an example of an indirectly immersive reality game. In an indirectly immersive reality, the user is not directly immersed, but is inside something that is immersed. Examples include an underwater submarine experience in which the user is inside a dry submarine which itself is immersed in water. Another example would be a hydraulophone played in a glovebox to keep the user dry. We have built a variation of hydraulophone, for example, which resembles a piano keyboard in which the keys are tubes or hoses of water. The instrument is played by pressing down on the water tubes to restrict the water flow or change properties of its flow. This form of hydraulophone can be played completely dry with no water getting on the user's

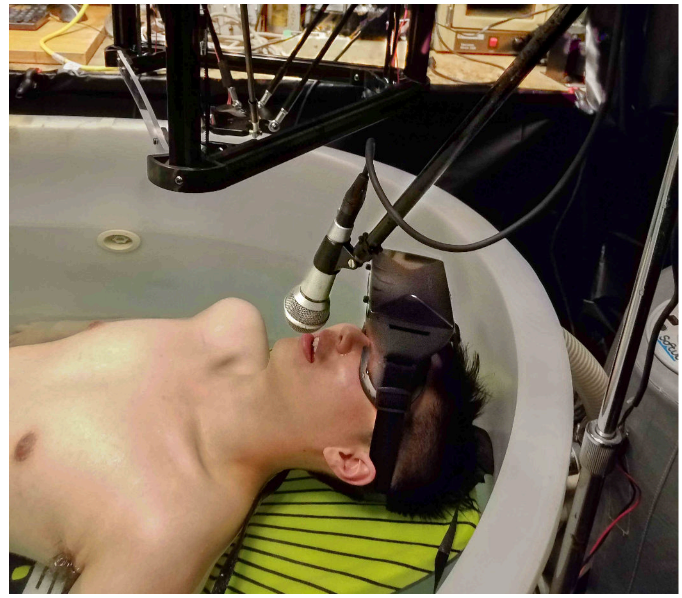

Fig. 5. Sensory Reprivation™ tank setup for collaborative throat-singing meditation game across networked sensory-deprivation tanks. Note the 3D SWIM and microphone.

fingers. This also allows other hydralic fluids such as oil to be used to produce the sound and the nerve stimulation. Hydraulophones typically operate in the 110 CPS (Cycles Per Second) to 330 CPS range. This is from the musical note "A" to the musical note "e" (one octave above "E"). Nerve stimulators and tactile actuators often operate around 200 CPS, so the hydraulophone is directly in the range in which the water vibrations can be felt most readily.

In another variation of water based fitness, a floating VR/AR or ZR system was constructed using a fitness ball inside of which a user exercises, as shown in Fig. 9. There is a camera that sees patterns or indicia marked on the ball, to track its position, and a processor that determines, computationally, how far the portion of the ball under the user's feet has moved. The indicia are infrared-visible markers that are visible to an infrared camera for tracking purposes without detracting from the aesthetics of the experience, and without obstructing the user's view, in situations where that view is being augmented (in VR, the experience takes place in a dark room so that the user is isolated from other experience, or, alternatively, a white translucent but not transparent ball is used).

The processor computes tracking information and renders it to either a VR headset worn by the participant, or to a a data projector that projects patterns onto the ball, or to a combination of a data projector to project near-field information, and an augmented reality headset to project far-field information.

In some of the experiments, the walls of the room were painted white, and data projectors were used to project to the room walls. In this way there are projectors facing the ball for nearfield data, and projectors facing away from the ball (toward the walls) for far-field data display.

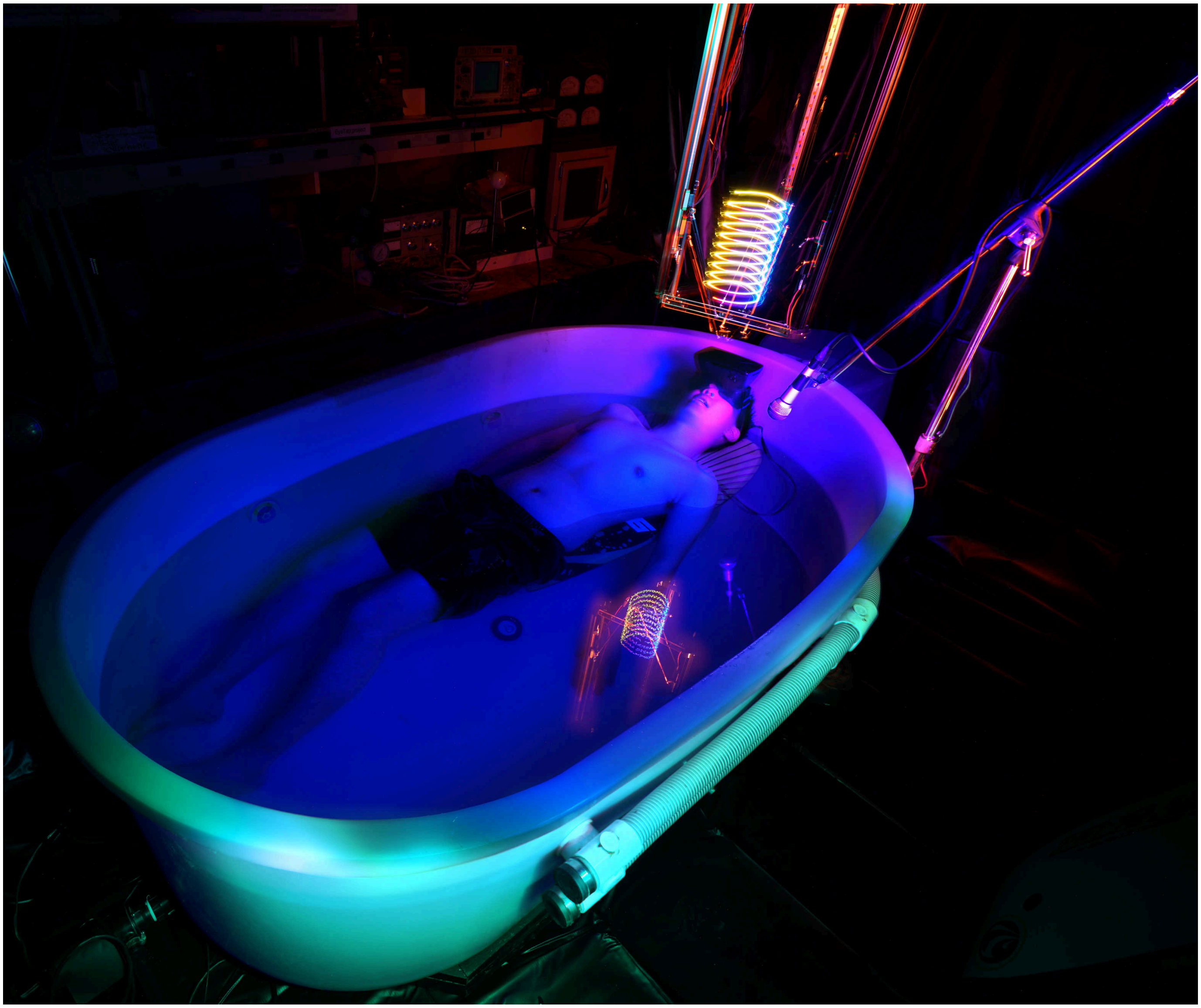

Fig. 6. Collaborative throat-singing meditation game across networked sensory-deprivation tanks. Apparatus traces out the helix pattern of a pure tone note, while the participant wears a VR headset to stabilize the visual exposure.

The processor performs a spherical transformation that renders a view as it would appear from where the user is positioned. In some experiments a camera was used to track the user's exact position and render for the user-position. In other experiments, a wearable sensor worn by the user tracked the user's position.

A signaller allows the user to control aspects of the game, and also allows the user to signal when he or she wishes to be let out of the ride, should he or she not wish to remain to the end. Typical rides in a waterball are on the order of 10 minutes, but if a user is in need of exiting prior to that time, an emergency stop indicator on the signaller may be used. A wearable sensor monitors the health of the user, and allows an attendant outside the ball to make sure the user is OK. The processor is also responsive to a water sensor, installed in the pool, in which the ball floats.

Thus we have both direct and indirect immersion/submsersion, as a basis for mersive reality.

In this paper, we build on these early concepts of immersive and submersive reality.

IV. Sub/Im/Mersive VR Singing + Meditation Game

Singing a steady tone ("*OM*") is a popular meditation technique, and often groups of people do this together. Frequency differences between various participants are captured by the brain, and this can occur in a spatial pattern (e.g. such that the left and right ears hear nearby but slightly different frequencies). This is called a binaural beat frequency [20]. When this frequency falls around 8 Hz, it is reported to have an entrainment effect on the brain, which can be a meditation

Fig. 7. Mersivity™ tank in MannLab Shenzhen. Here a linear 2D SWIM (visible in red, in the background, with SWIMwave in green on the TV screen at left) is used instead of the 3D SWIM at MannLab Toronto (compare with Toronto setup in Fig. 6).

aid [21]. Accordingly, we created a game based on meditative vocal collaboration across isolation tanks.

The game is played by one or more players, each wearing a VR headset and floating in their own tank. One player (or a computer) initiates a note or slow chirp and players try to sing the same note or follow (track) the chirp. Scorekeeping is by ratio of rabsement (strong voice) to phabsement (integrated phase error): $\int Rdt/\int|\delta_\phi|dt$ [1]. The sound wave interference between the speaker and each player is phase-coherently captured by a special lock-in amplifier, as shown in Fig. 1 (right) [22]. Each player sees the interference pattern in their VR headset and can control their pitch according to this feedback. Phenomenological Augmented Reality technology [22] is used along with a robotic arm to plot the wave pattern (a pure tone is a perfect helix, extruded in the Argand plane) in the room for them to see prior to donning the VR headset. The 3D plotting device is suspended above each tub, so the user can accustom to it prior to donning the VR glasses, and thus strengthen the reality of being inside the soundfield.

We also have a single-player mode in which the player competes against their own voice as previously recorded, or against other recorded voices. The score in the game is the reciprocal time-integral of absolute phase.

V. Mersivity™

We proffer the new field of Submersive Reality in which we fully immerse ourselves. By immersing ourselves physically and fluidically, we attain a much stronger coupling between our bodies and the immserive experience around us. With one's feet on the ground, one can still believe the things we see in our eyeglass are not real. But when floating, we attain a new height of connection to the synthetic reality. One example simulation we created as an app to swim with sharks and avoid being eaten. We were able to, in a small wading pool, create an illusion of vastness and total immersion. See Fig. 10

We also created a virtualization of the MannFit (Integral Kinesiology) system. The concept of IK (Int. Kin.) was originally based on stopping water leaks, either directly, or with a ball valve or other valve that requires being held at a certain angle to stop water flow. By simulating this in a virtual environment, we were able to create similar physical fitness benefits without the need to use water or wear bathing suits or provide a place for people to change and dry off, etc.. However, in the presence of original (wet) IK, we can add also the virtual elements as well. For example, we used a wobbleboard in a pool, where participants stand on the board

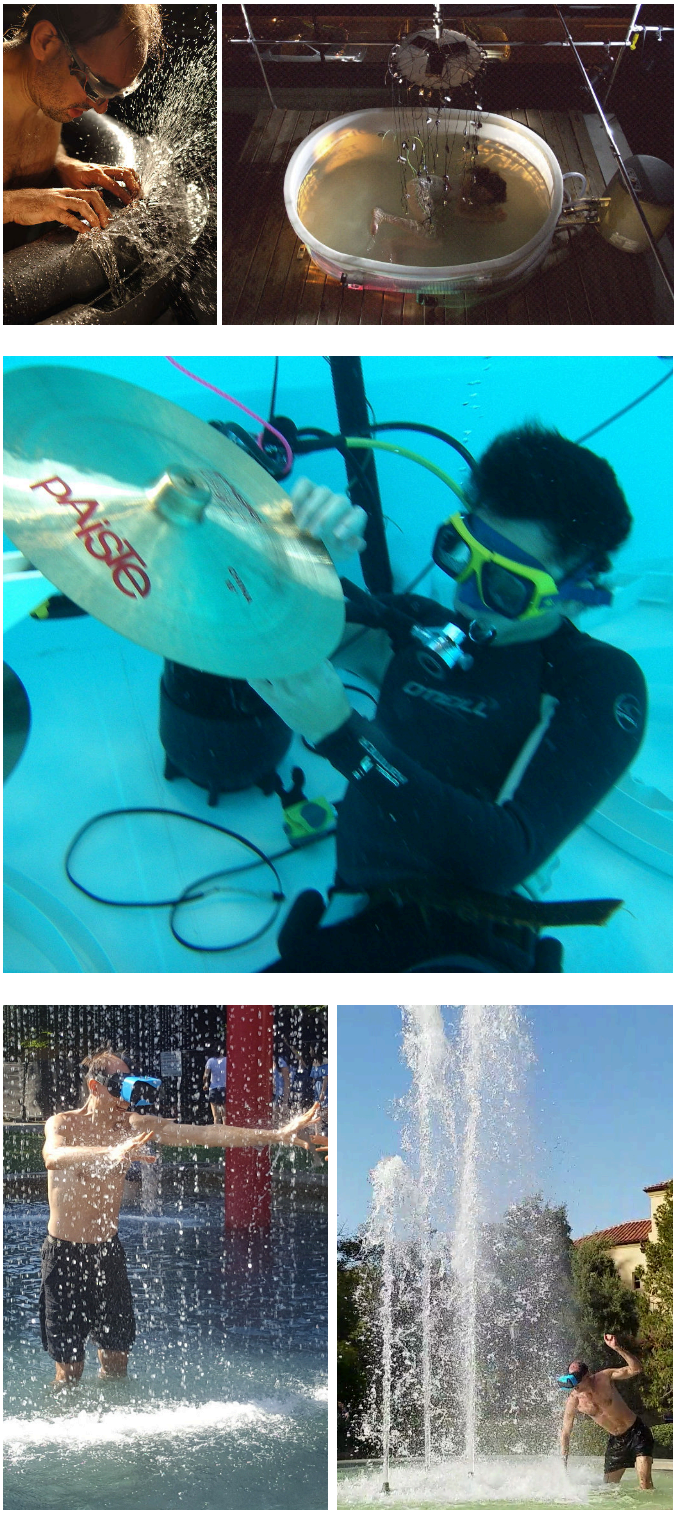

Fig. 8. World's first underwater AR/VR/MR/XR/XYR/ZR and interactive underwater multimedia experiences [13], [14], [15], [16], [19], [2]. Top left: world's first underwater AR (Augmented Reality) headset, completed 1998, used for hydraulophone (underwater pipe organ) training as a form of physiotherapy. Top right: World's first VR/AR/MR/XR/XYR/ZR float tanks, wirelessly networked in a worldwide public exhibit on 2003 May 22nd. Center: ICMC 2007 immersive real/augmented/virtual/multimediated reality music concert. Bottom: Deadheading as described also in the "Effectiveness of Integral Kinesiology..." paper of this conference proceedings.

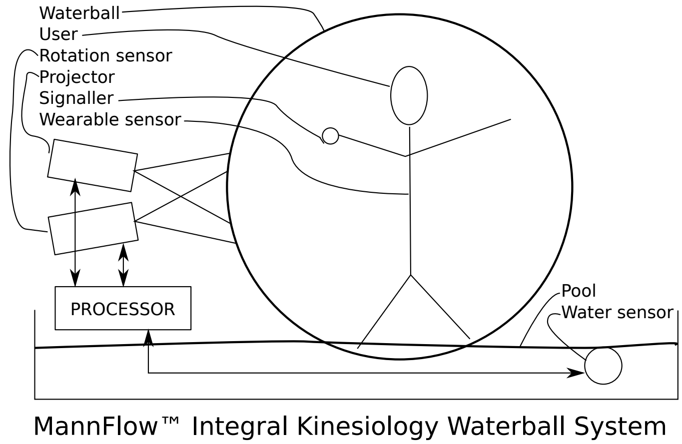

Fig. 9. **Indirectly Immersive/Submsersive Reality:** The user stays dry inside an air-filled ball while the ball floats on water. The result is a floating experience while imagery is projected onto the ball, as well as the walls of the room in which the user is playing. In addition to these two or more depth planes, an AR headset allows further depth planes for a complete lightspace™ (tensor outer product of a lightfield with a time-reversed lightfield) experience.

Fig. 10. Underwater virtual reality with the MannLab Mersivity™ headset turns a cheap $20 wading pool into a massive and compelling fully immersive and submersive MR/ZR experience.

in the pool while wearing a VR headset with their head above water. The virtual world is one of a room filing up with water due to the leak that most be stopped by keeping the board level.

Other experiences include interacting with water jets, as shown in Fig. 11 (see also our co-pending paper "Effectiveness of Integral Kinesiology...").

We also created another concept, "Liveheading™" akin to deadheading, but with a tee fitting so that when the jet is blocked, water is diverted through a side discharge across at Karman vortex shedder bar and Nessonator™ [23], as shown in Fig. 12.

VI. Submersive Reality

Our fully submersive reality headset was developed for audiovisual mediation and interaction, as shown in Fig. 13. This will be the topic of ongoing future research reports and publications, as we fully develop our Hydralikos™ installations in Shenzhen and Xiamen.

VII. Conclusion

We presented a novel VR meditation biofeedback game where players are each isolated in their own tank to share a

Fig. 11. Interacting with water jets. Top left: VR fitness game in which the objective is to use the hands and fingers to completely surround the water as close as possible, and run the hands along the curve of the water jet without ever touching it. This is a form of Integral Kinesiology™ (see our paper entitled "Effectiveness of Integral Kinesiology..." in this same conference proceedings) similar to the "buzzwire" game in which a player moves a circular metal ring along a serpentine wire without touching the wire. Upper right and bottom: Deadheading™, as described in the "Effectiveness of Integral Kinesiology..." paper.

collective reality while isolated from everything else, resulting in an immersive/submersive fluid-user-interface and VR experience. Such new interactive experiences suggest a possible future direction for VR along the lines of sensory attenuation as an important design element. This also underscores the importance of our "All Reality" framework of multimediated reality (ZR), and why we need to think beyond AR, VR, XR, and XYR.

VIII. Acknowledgements

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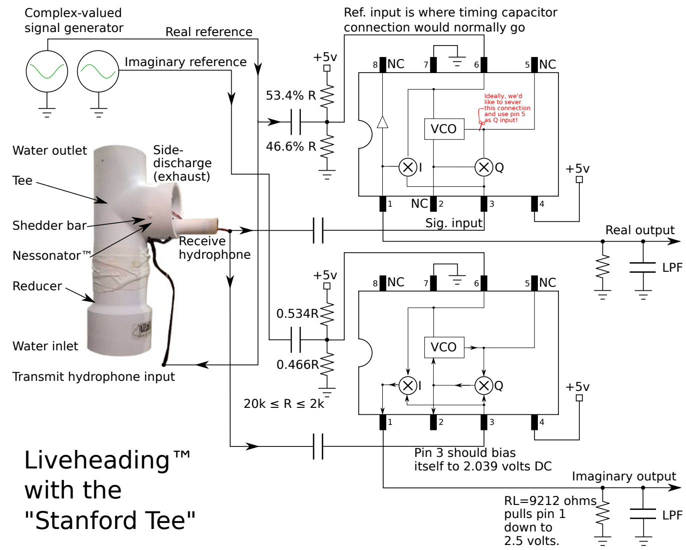

Fig. 12. Liveheading™ with the "Stanford Tee". System developed by S. Mann, Visiting Full Professor, Stanford University, for use with Stanford's Tanner fountain (the large fountain at the main entrance to Stanford University), in accordance with Stanford's "fountain hopping" tradition. A 1.5 inch Tee fitting is connected to a 2 inch to 1.5 inch reducer that fits over the tallest of the four water jets. Blocking the "Water oulet" diverts water to the "Side-discharge" past a sheddar bar that feeds into a Nessonator™ (hydraulic resonator). A pair of hydrophones, facing each other, are placed in the water stream of the side-discharge, and a "Receive hydrophone" picks up the sound of the water that hits it. Additionally, a "Transmit hydrophone" transmits a signal into the water, which travels with the water to the "Receive hydrophone". A low-power battery-operated (USB powered) lock-in amplifier is made from a pair of LM567 tone decoders. Pin 3 of each tone decoder is connected through separate coupling capcitors to the "Receive hydrophone". The tone decoder, in normal operation, using a capacitor connected to pin 6 and a resistor connected to pin 5 to set the timing (RC circuit for VCO). Instead, a reference input is suppied to where the capacitor would normally be connected. The reference input is capacitively coupled (separate capacitors for real and imaginary tone decoders) to the inputs. The sensitvity of the device can be greatly enhanced by biasing pin 6 to about 46.6 percent of the supply voltage. A voltage divider creates a 46.6 % and 53.4 % split. This can be done with two resistors R_u (up) and R_d (down). A resistor R_u in the 1k ohm to 10k ohm range works nice, whereas for R_d a combination from 1k ohm and 12k ohms in paralell, up to about 10k ohms and 120k ohms in parallel works well. If it were possible to redesign the chip or modify it by severing the output of the VCO to disable its effect on the quadrature multiplier, the apparatus could be made from a single LM567 chip. Pin 1 is normally used for the output filter capacitor, but in our use, we take the final output there. Internally there is approximately 4.7k ohm pullup so there needs to be a pulldown to get the output nicely centered. Due to asymmetry, we observed the optimum pulldown resistance to be 9212 ohms, resulting in an output nicely centered at 2.5 volts, so that it can be easily followed by additional amplification. A capacitor is used as the LPF (Low Pass Filter) element. Since the resistor MUST be 9212 ohms, the capacitor is the freely chosen element to decide on the cutoff frequency, depending on the highest frequency of the water sound vibrations desired to be sensed. The real and imaginary outputs then drive a microcontroller that feeds into the immersive VR game. The hydrophones are Sensortech Canada SQ34 which we found to load the signal generator strongest at 81kHz and 930kHz, but as a pair, transmit and receive best at 12.5kHz (1%), 23.8kHz (0.9%), 1470kHz (3%), 2120KHz (3.5%), 3084 (7.8%), and about 5000kHz (70% of the input voltage received at output).

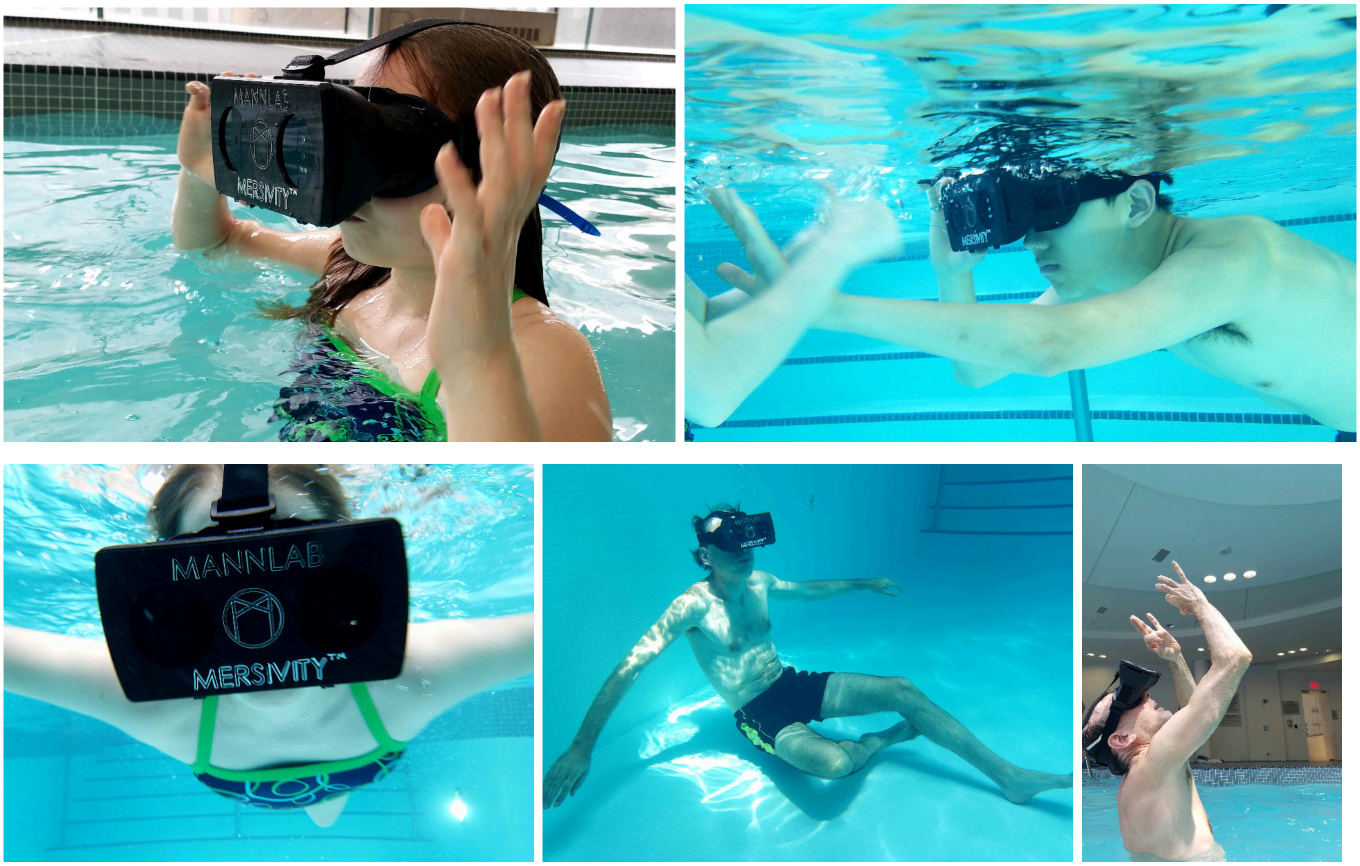

Fig. 13. MannLab Mersivity™ headset

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