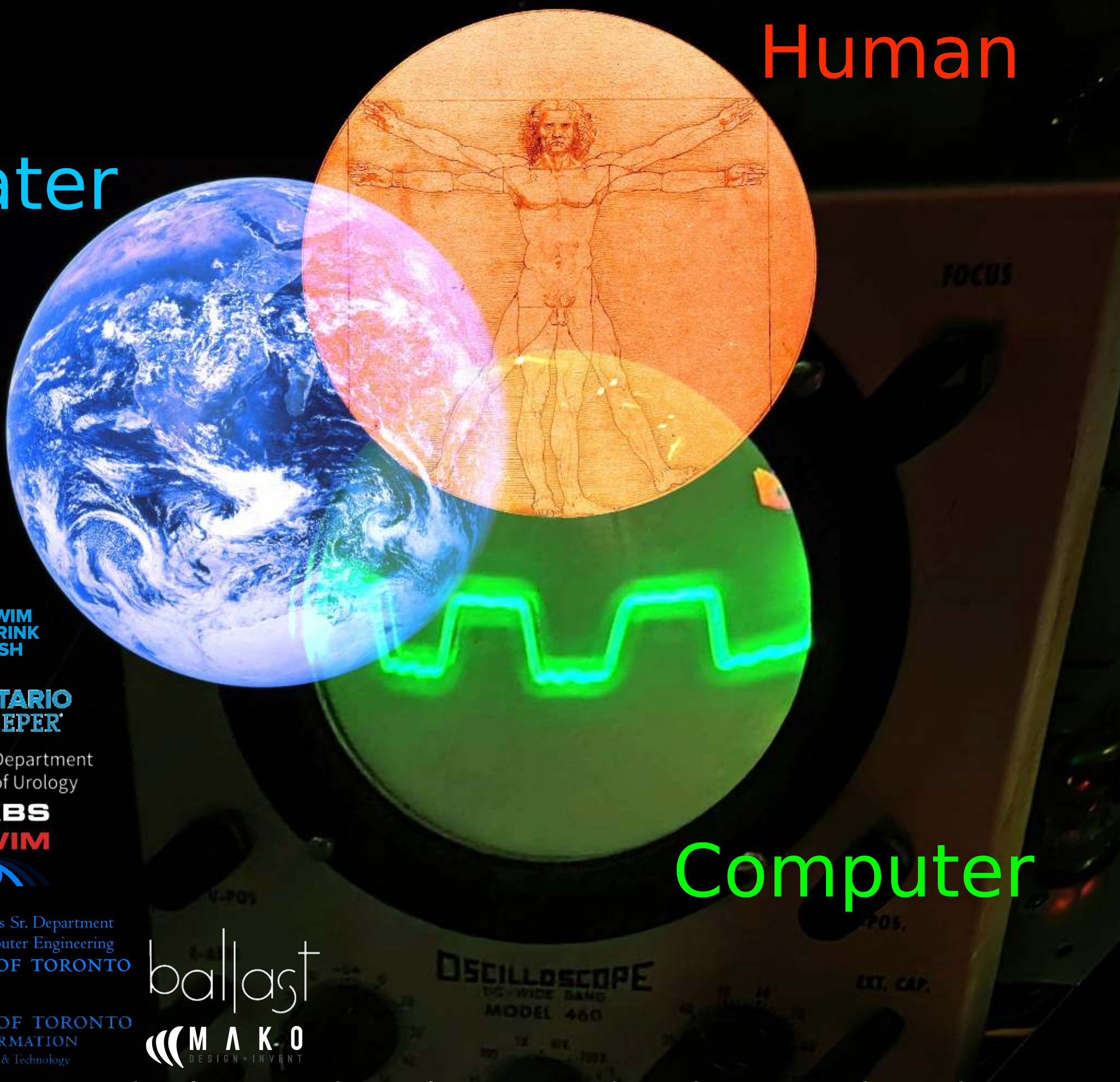
WaterHCI 2021

Michel Caron, SwimOP = Swim at Ontario Place

Proceedings of the 23rd annual Water-Human-Computer Interface Deconference™



Earth and human pictures from Wikimedia Commons

Online and at Ontario Place Outdoor Classroom, Thursday December 9th, 2021

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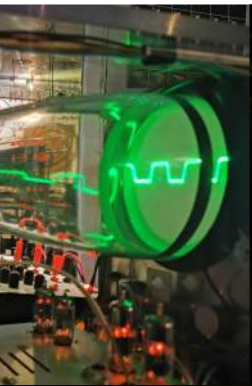
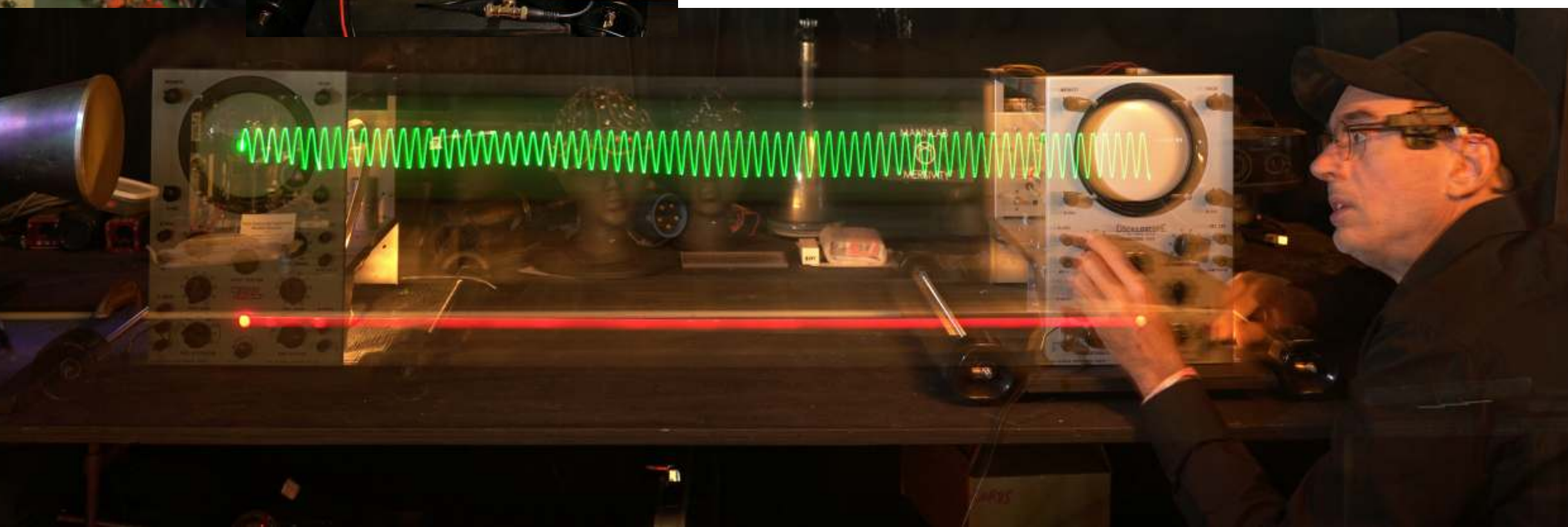
Water and Electricity?

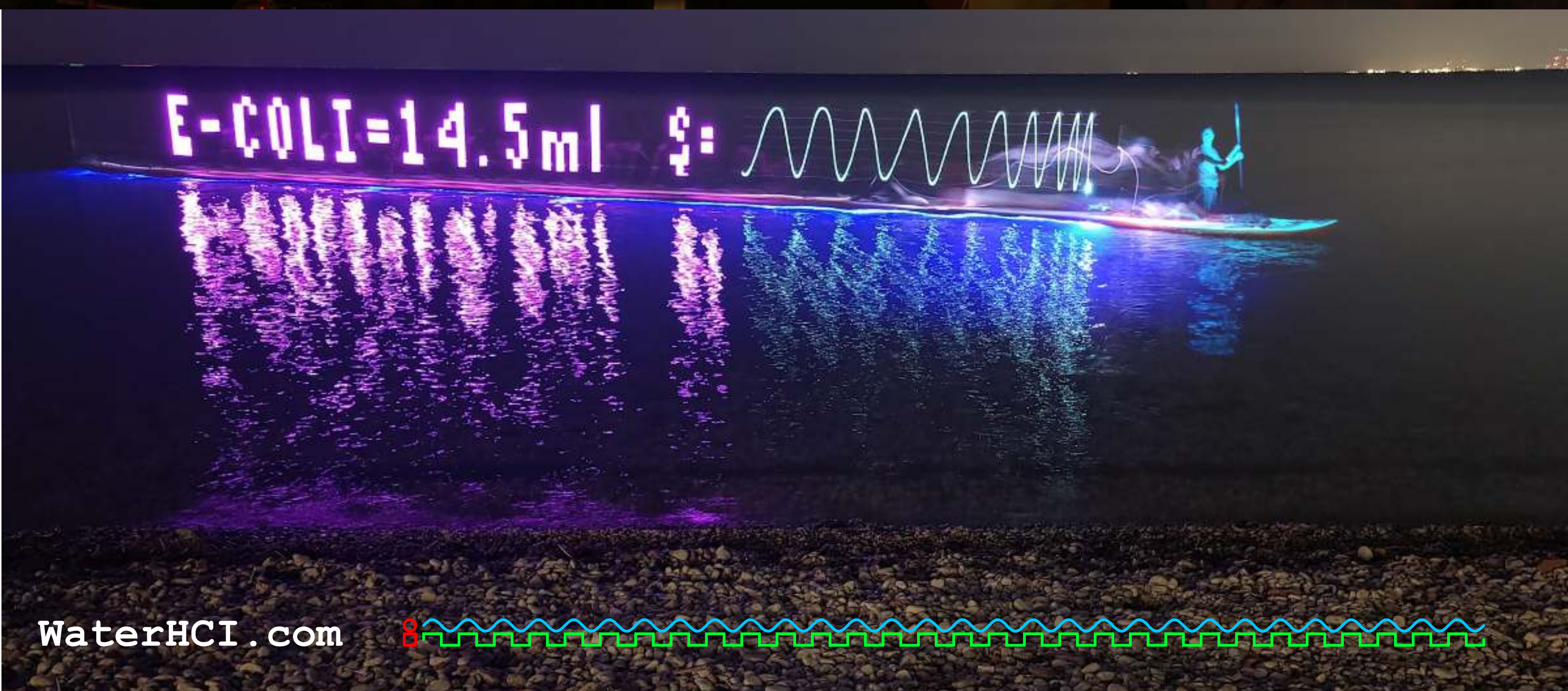


When the concept of Water-HCI (Water-Human-Computer-Interface) was born in Canada in the 1960s, the green glow of the round-screen CRT (Cathode-Ray Tube) required thousands of volts.

Pictured here is the SWIM (Sequential Wave Imprinting Machine), an early interactive Water-HCI system, for marine radar. It uses a 5UP1 CRT running at 2,600 volts DC. This required it be operated aboard a vessel to keep it dry.

Modern SWIM (bottom of page) runs on 5 volts DC, is waterproof, and can operate underwater or on a precarious vessel like a SUP.





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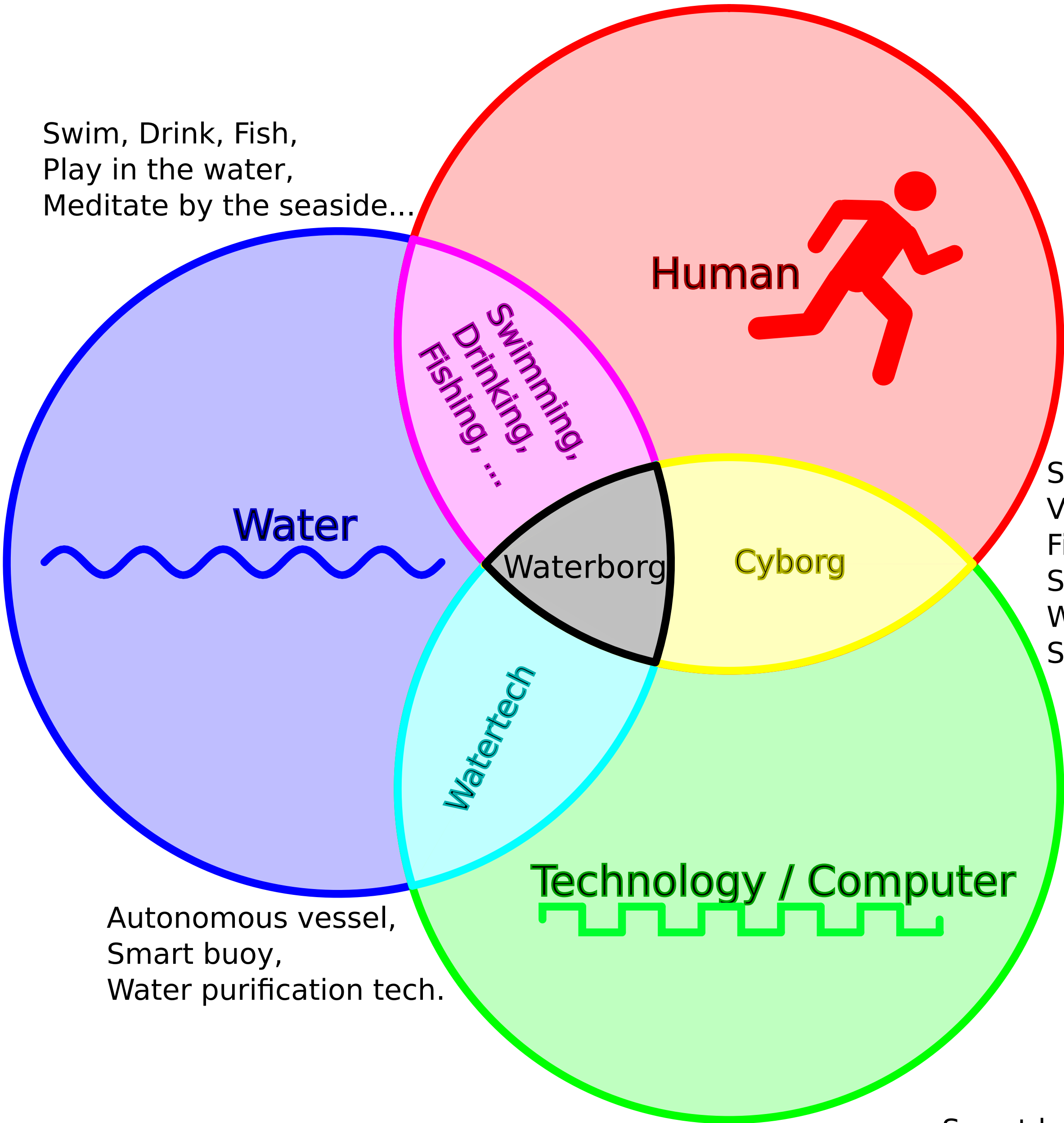
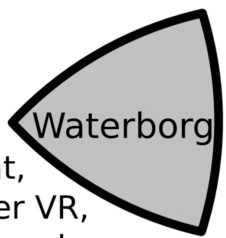
Swim, Drink, Fish,
Play in the water,
Meditate by the seaside...



Smartwatch,
VR headset,
Fit-tracker,
Smart shoes,
Wearables,
Smart vehicle.

Autonomous vessel,
Smart buoy,
Water purification tech.



Smart boat,
Underwater VR,
Smart swim glass,
Smart float tank,
Waterproof smartwatch,
Interactive shower,
Smart aquatic play...

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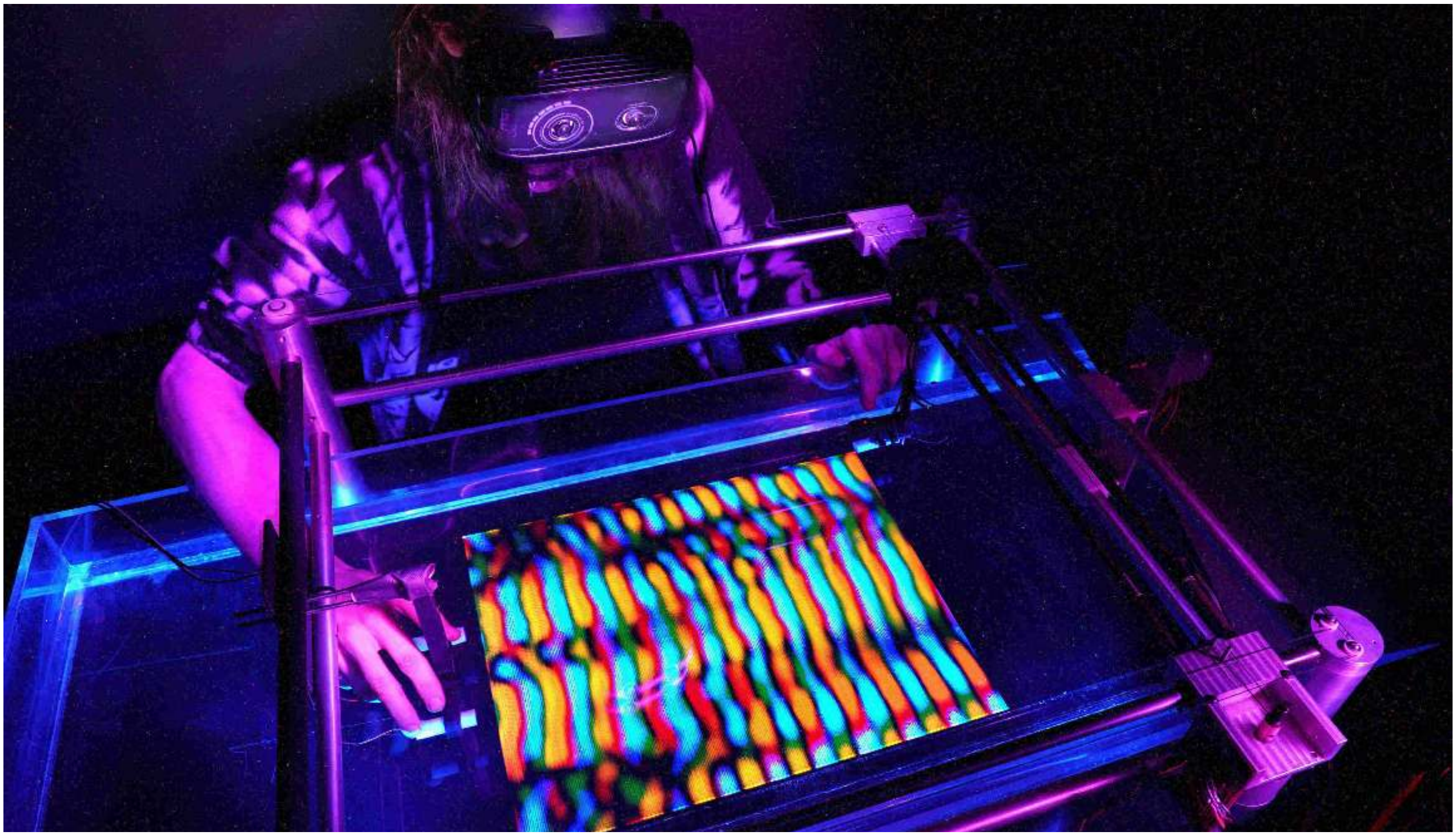

Proceedings of the 23rd annual WaterHCI DECONference

WaterHCI 2021

Fluid User Interfaces

Exploring the boundary between self and environment through cyborg-water interaction.

Thursday December 09, 2021

Toronto, ON, Canada, online (www.waterhci.com) and at the beach at Ontario Place

DOI (Digital Object Identifier) = 10.5281/zenodo.5769045
https://zenodo.org/record/5769045

Overview of the 23rd Annual DECONference

Toronto, Ontario, Thursday December 9th, 2021,
10am to 6:30pm Eastern Standard Time

The Water-Human-Computer Interface DECONference is an annual conference series that began in 1998 at University of Toronto's Department of Electrical and Computer Engineering in collaboration with the then McLuhan Program in Culture and Technology, hosting DECONference0 in 1999, with an initial emphasis on pandemic preparedness.

Decon1 took place in 2000 at University of Toronto and Decon2 took place in 2001 at Gallery TPW on 80 Spadina Ave in Toronto. Decon3 was hosted at Deconism Gallery in Toronto, August 2002 as its inaugural exhibit.

Originally a series of playful art installations on culture and technology, the ideas, inventions, and designs arising from the DECONference series were presented on Capitol Hill in Washington DC and informed the design of hospitals for pandemic preparedness.

This year the 23rd annual WaterHCI Deconference is Hosted by the McLuhan Centre Working Group on Equiveillance, at University of Toronto, led by:

- Steve Mann (Engineering)
- Rhonda McEwen (iSchool)
- David Naylor (Medicine)
- John Griffiths (Psychaitry, CAMH)
- Kristen Bos (Technoscience Research Unit)
- Amir Adnan Ali (Engineering)
- Beth Coleman (UTM)

Schedule (Eastern Standard Time)

- 10am: Introduction + musical performance (S. Mann and Dr. Eugene Draw)
- 10:30am: Robert Thurmond, World's most advanced aquatic safety system
- 11:00am: Morning break
- 11:20am: Leif Oppermann
- 11:40am Kevin Mako
- 12noon - 2:20pm: Break for a lunchtime swim, departure for Ontario Place beach, come try our cyborg technologies!
- 1pm: Icewater Swim at Ontario Place TeachBeach™ (for location, see waterhci.com/where/); Demo of underwater VR/AR/XR (eXtended Reality) by Cayden Pierce
- 1:30pm Return from Ontario Place
- 2:20pm: Craig Travers, Vuzix SmartSwim
- 2:40pm: Steve Hulford, swam over 200km in Lake Ontario
- 3pm: Keynote, Dr. Seung-min Park, Stanford University, World's smartest toilet
- 3:30pm: Washroom break (after smart toilet talk)
- 3:40pm: Mark Mattson, Swim Drink Fish
- 4pm: Mark Fox, University of Toronto, Water and Smart Cities
- 4:30pm: Ryan Janzen, Fluidity in Music, Physics, and High-Speed Transportation; Hydraulophone performance.
- 4:50: Washroom break (after hydraulophone performance)
- 5:00pm (2pm Pacific) Derek Lam
- 5:20pm (7:20am Dec. 10 Tokyo time), Tomoko Yonezawa, Fluid interaction with musical toys
- 5:40pm (9:40am AEDT), Florian 'Floyd' Mueller, Towards beginning to understand WaterHCI
- 6pm (3pm Pacific): Atlas Roufas, Ballast Technologies, Closing Keynote, VR for waterparks

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https://zenodo.org/record/5769045

Water-Human-Computer-Interface (WaterHCI): Crossing the Borders of Computation, Clothes, Skin, and Surface

Steve Mann, Mark Mattson, Steve Hulford, Mark Fox, Kevin Mako, Ryan Janzen, Maya Burhanpurkar, Simone Browne, Craig Travers, Robert Thurmond, Seung-min Park, Atlas Roufas, Cayden Pierce, Samir Khaki, Derek Lam, Faraz Sadrzadeh-Afsharazar, Kyle Simmons, Tomoko Yonezawa, and Ateeya Manzoor*

Abstract

Water-Human-Computer Interface (WaterHCI), or, more generally, Fluidic-User-Interface (i.e. including other fluids) is a relatively new concept and field of inquiry that originated in Canada, in the 1960s and 1970s, and was further developed at University of Toronto 1998 to present. We provide a taxonomy of the various kinds of water-human interaction, which we call the "Interface Taxonomy", as it is based on the crossing of interfaces (boundaries). We identify important past, present, and future contributions and trends in WaterHCI from around the world, and identify grand challenges of this new discipline.

1. Introduction

Water is essential to human life, and in fact humans are composed of mostly water. The brain and heart are composed of 73% water, and the lungs are about 83% water [1].

The worldwide water shortage and the associated health impacts create a need to invent creative new technologies that are both useful and sustainable and consider water as an integral part of our bodies.

Organizations like **Swim Drink Fish**, an internationally-recognized charity that has connected 7-million people to their local waters and has activated about 2-billion dollars in restoration work are vital to safeguarding our waters [www.swimdrinkfish.ca].

Interestingly, the name of this organization suggests a useful taxonomy or ontology for the three ways humans can interact with water:

- we can enter the water, i.e. swim, wade, dip, dunk, or bathe in the water;
- the water can enter us, i.e. we can drink water or eat food with water content or receive liquid-based medication;
- we can enjoy the water while remaining separate from it, e.g. we can go fishing from a bridge or boat, we can sunbathe at a beach, or we can sit by the water and meditate to the sound of the waves, for example.

See Fig 1

*We wish to thank the Marshall McLuhan Program in Culture and Technology, AMD, and Vuzix

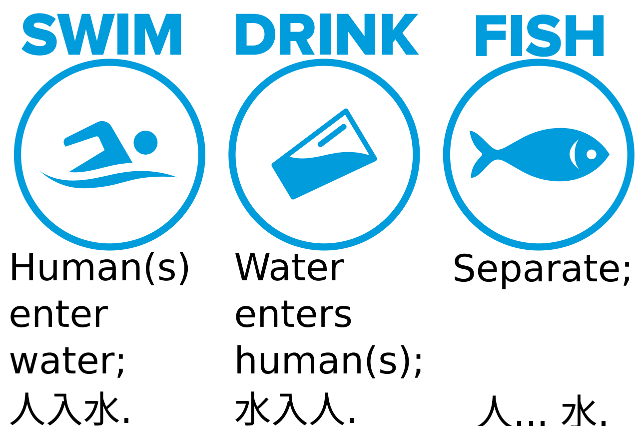

Figure 1. Swim Drink Fish is an internationally-recognized charity active in 11 countries. Its name and logo suggest a simple taxonomy or ontology of the three ways that humans and water can interact: Humans enter water (e.g. when we swim, dip, dunk, wade, or bathe); Water enters humans (i.e. when we drink); and as separate entities, e.g. when we go fishing or sunbathe on a beach or sit and meditate by the water's edge. These three concepts are so fundamental to all human cultures and civilizations, and make sense in nearly any language. For example, in Chinese, the three words "Human", "Enter", and "Water" are each represented by a single character, and when we put them together, we construct a grammatically correct sentence: "人入水" means "People enter the water" and "水入人" means "Water into people".

1.1. Interfaces (Air-Water, Human-Machine, . . .)

This paper is about *interfaces*, in both senses of the word. The word "interface" has 2 meanings:

- the surface boundary between two bodies or phases of fluid, e.g. the water-air interface;
- the place where independent systems meet and interact with each other, e.g. human-machine interface or human-computer interface/interaction (HCI);

This double-entendre is fully embodied in the hydraulophone, a form of inclusive aquatic play technology for the blind and seeing impaired, as well as for the hearing impaired. See Fig 2.

One important feature of the hydraulophone is that it facilitates aquatic play using very little water. Compared to other

Figure 2. Hydraulophone installation at the Canadian National Institute for the Blind (CNIB) [2]. The hydraulophone is a human-water-machine interface that is highly tactile. The sound vibrations in water can also be experienced by the hearing impaired, e.g. a deaf musician is able to experience sound through the natural impedance match of vibrations in the water, since the human body itself is mostly water (i.e. is of like acoustic impedance) [3].

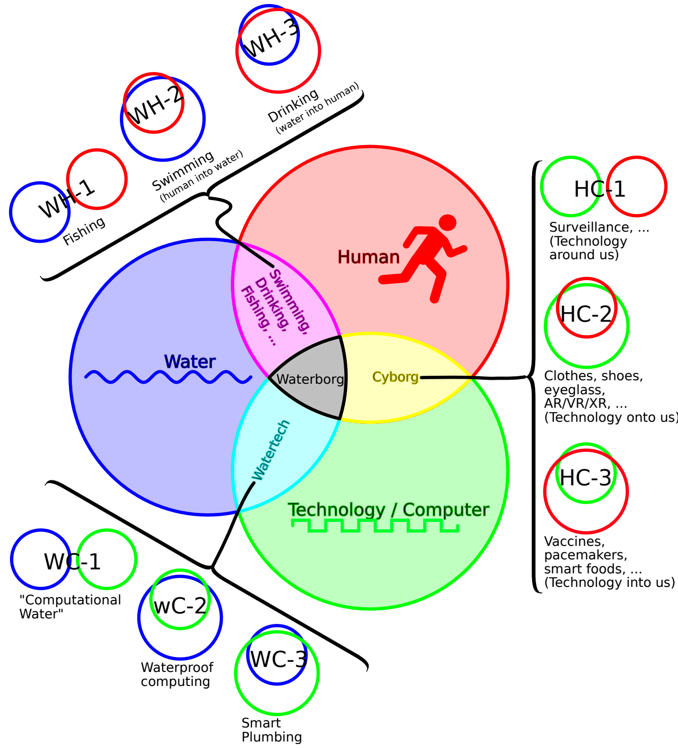

Figure 3. Interfaces (boundaries or "borders") between Water, Humans, and Technology/Computing. The blue circle represents water. A red (or brown or tan or pink or orange) circle is used to represent the human, as red is the color of our blood which imparts a reddish or brownish or pinkish or orangeish (i.e. not green or blue) color cast to our skin. Technology / Computers are denoted by the green circle, as green is traditionally the color of early computer interfaces. Humans have interacted with water for thousands of years, swimming, drinking, fishing, etc. At the same time, humans have also evolved technologically. Technologies like shoes, clothing, and eyeglasses, and more recently, computation, have brought us into the cyborg age. But many of these technological extensions of our minds and bodies tend to be left behind when we engage with water. We don't normally swim or bathe fully clothed. Although there is a great deal of technology used with water, such as water purification, water management, etc., water-human-computer interaction is a matter of relatively recent history over the last 50 years or so, and this full water-human-computer interaction interaction falls at the center of the three circles.

water play features and installations that spray large quantities of water, the hydraulophone achieves a profound satisfaction from a small amount of water used or recirculated.

The hydraulophone exemplifies a water-human-machine interface, whether with a fully acoustic hydraulophone, or with a computationally equipped, augmented, or mediated hydraulophone. The terms "Fluidic User-Interface" and "Fluid User Interface" were coined and defined in work published in 2005 [4], in the context of fluidic-human-computer interaction or fluidic-human-machine interaction. "Fluid User Interfaces" are interfaces that allow direct contact with fluid content, sensing of fluid, and input via fluid (e.g. water, but also including other liquids or gases as user-interface media, e.g. jets of compressed air). Thus, water in a "Fluid User Interface" serves as a possible input medium and output medium. As humans are made of water, this viscerally represents technologies which become part of the self, as water is us and we are water, so, too, our interfaces and machines are (or at least involve) water.

1.2. Taxonomies, ontologies, and passion versus discipline

We summarize and organize (through taxonomies, graphs, etc.) past, present, and future work and directions (toward grand challenges) that fall at the intersection of water, humans, and technology/computing. This work, by its very nature, goes beyond being interdisciplinary, cross-disciplinary, multi-disciplinary, or transdisciplinary, into what might better be described as anti-disciplinary or, to say what it is rather than what it isn't: inter/cross/multi/trans/meta-**passionary**. Passion is a better master than discipline, to paraphrase Einstein's "Love is a better master than duty".

In particular, WaterHCI (Water-Human-Computer Interaction/Interface/Intersection) brings together art, science, technology, health, well-being, spirituality, music, theatre, sport, sociology, social-commentary, human-rights, justice, legal, and philosophical elements into a framework, philosophy, and worldview that celebrates water as playful, curative, healing, cleansing, sacred, practical, and essential.

1.3. Boundaries and interfaces

Consider the various boundaries and intersections between water, humans, and technology/computers, as illustrated in Fig 3 where we use blue to denote water, red (or reddish, blood) to denote the human, and green, the color of early computer screens, radar screens, printed circuit boards, and oscilloscope screens, to denote technology, as shown in Fig 4.

1.4. Water-Human Interaction

For thousands of years humans have interacted with water in various ways. Raffe et al. provided a taxonomy of interactions

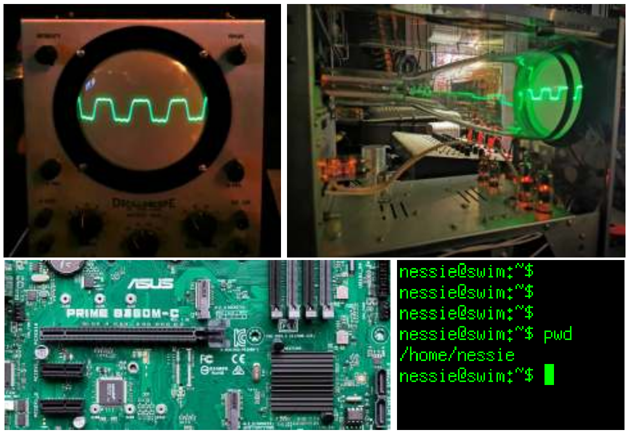

Figure 4. **Green is the color of computers and technology.** (Top row) Interactive educational installation from 1973 (PASCO) providing real-time interaction with mathematical Fourier series coefficients to study additive waveform synthesis. Early oscilloscopes, radar screens, computer screens, and the like provided a graphical (often vector graphics) or text-based user-interface by way of a green phosphor on a cathode ray tube such as the one shown here from the 1950s retrofitted with a 1930s style CRT (pre-aquadag era). (Left) front panel. (Right) inside of the interactive vector graphics display (Eico 460 oscilloscope with transparent CRT for teaching purposes), showing the cathode ray tube and other vacuum tubes to support its operation. (Bottom row) Over the years the same green color continued to be associated with computer-interfaces. Here is a computer circuit board and the quintessential green glow of a computer screen, typical of monochrome computer screens.

with water based on degree of separation or contact that ranges from being near water, to being underwater [5]. Mark Mattson takes this concept a step further by proposing the "Swim Drink Fish" taxonomy: we can be near or upon the water (fishing); we can be entering or in the water (swimming); or the water can be entering or in us (drinking) [6]. In Fig 3 we adopt the Mattson taxonomy at the intersection of humans and water. We number these 3 kinds of Water-Human interactions as follows:

1. Denoted by blue circle (water) and red circle (human) as separate: Interacting with water from a distance, as we approach a lake or river, sightseeing, sitting at the side of a beach, or fishing from land or boat, we call Type 1 Water-Human interaction, WH-1, as shown in the upper left corner of Fig 3.

2. Red circle (human) inside blue circle (water): As we enter a body of water and experience bathing, washing, wading, swimming, or the like, or other forms of immersion or partial immersion in water, we call this WH-2 (Water-Human interaction, Type 2) which denotes humans entering water, or humans in water (humans "into" water).

3. Blue circle (water) inside red circle (human). Finally when we get into the water and swallow a mouthful of water (accidentally while swimming or intentionally while drinking), or, when outside of the water and swallowing water (e.g. drinking from a vessel or water pipe) we call this WH-3, which denotes water into humans. As an example, consider the musical drinking fountain at DECONference 2002 that used a laminar water jet to convey sound through bone conduction into the teeth of those drinking from it. Thousands of years ago humans went to bodies of water to drink, until about 8,000 years ago in the new-stone age when drinking vessels were invented. Then about 3,000 years ago aquaducts were invented to move water. WH-3 is also an area where technological progress is of great importance to human health.

1.5. Water-Technology/Computer Interfaces

In a similar way we have three kinds of water-technology (water-computational) interaction:
WC-1: Water and computing separated but working together. Examples include the Smart Beaches projects in which surveillance cameras monitor a stretch of beach and apply machine learning algorithms to monitor beach safety, perform automated drowning detection, automatic shark detection, riptide detection, and the like. Similar systems also exist for pools, e.g. automated drowning detection using above-water cameras;
WC-2: Technology enters the water, e.g. automated drowning detection systems using underwater cameras;
WC-3. Water enters the technology, e.g. smart toilets with automatic flush, smart automatic handwash faucets that use computer-controlled solenoid valves.

1.6. Human-Tech/Computer Interaction

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``Very funny, Scotty.  Now beam me
up my clothes.''
== Sean Keogh, Bottoms Up:  A
Cheeky Look At Life
```

Technologies like clothing are so commonplace that their absence seems strange. Someday in the future if a machine were ever invented that could transport us across time and space, we'd be surprised if our clothes didn't travel with us, yet we would not expect the floor or ground or walls or trees to come with us. There's something special about certain technologies like clothes that become part of us. Technologies that become part of us are often referred to as "cyborg technologies".

1.7. Cyborgs existed a million years ago

Human inventions extend our capabilities. As we adapt to these technologies we become new beings for which Manfred Clynes coined the term "cyborg" (cybernetic organism) [7], his favorite example being a human riding a bicycle [8].

We proffer that if the canonical form of cyborg is a human riding a bicycle, that a human riding a boat is also a cyborg. The bicycle was invented June 12th, 1817 [9], a little more than 200 years ago, and the wheel was invented approximately 6000 years ago [10], but the invention of the boat dates back much further, to prehistoric times, more than a million years ago [11]. In this sense cyborgs have been around for more than a million years, long before homo sapiens emerged in Africa around 300,000 years ago [12]. It is interesting to also note that clothing was invented approximately 100,000 years ago, i.e. the invention of the boat pre-dates the invention of clothing. Thus a human in a vessel would likely have been the world's first

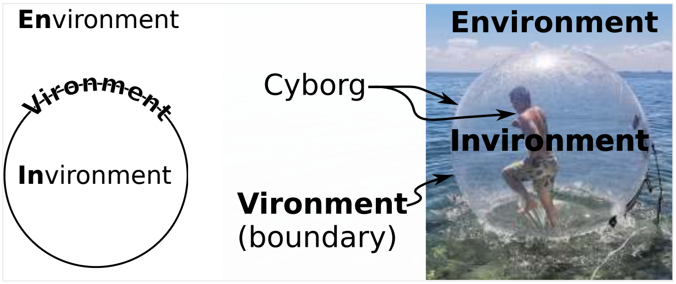


Figure 5. A human running in a waterball is a cyborg in the sense that, over time, the vessel functions as a true extension of the mind and body. The environment is that which surrounds us. The invironment is that which is not the environment, namely the space inside the ball which the human will perceive as part of them. Grid lines indicate distance in metres. The 2m (diameter) ball has a 1m radius that sets forth the boundary between the invironment and environment. This boundary is called the vironment.

"cyborg" and, therefore, there is an inextricable intertwining between cyborgs and water!

For the purpose of this paper let us consider the example of a human riding a paddleboat, or, perhaps another form of watercraft/vessel that is human-powered, namely the "water ball ride" (Fig 5 and 6).

A vehicle or vessel becomes part of us in the sense that when two boats (or cars) collide, one sailor (or driver) will yell at the other "You hit me!" rather than saying "Your vessel hit my vessel.". In this way sailors (and drivers) regard their vessel (or vehicle) as part of themselves, consistent with the Clynes concept of "cyborg". Our clothes, or vessels (or whatever we think of as part of us) define a boundary between us and that which surrounds us. We use the word "environment" to denote that which surrounds us, and "invironment" to denote that which is not the environment (i.e. us ourselves, as delineated by our clothes or vessel). Accordingly, the vironment is the boundary between the invironment and environment. The waterball is a good metaphor for this concept in general. Being approximately 6 feet or 2 metres in diameter, it creates an appropriate social bubble for CoViD-19 social-distancing during a pandemic. Whereas the waterball makes this boundary very explicit with well-defined edges for exactly 2-metre social-distancing (1 metre radius), other forms of technology have a more gradual transition between invironment and environment. Consider for example the HEADome™ first exhibited at List Visual Arts Centre, 24 years ago, October 7th, 1997 (Fig 7). and the Social-Distancer™ of DECONference 2020 (Fig 8).

Let us define the three basic kinds of Human-Computer interaction technologies with reference to Fig 3:

- HC-1: Interactions in which the computational and sensing technology surrounds us, e.g. interactive surveillance cameras in the environment around us create a "smart room" or "smart city" or the like (surveillance cameras have been in use since 1927 [14]);

- HC-2: more recently wearable computing has provided a form of cyborg technology that more directly becomes part of the human, giving rise to the field of wearable AI (wearable artificial intelligence) [15]. The Social-Distancer is an example of HC-2;

- HC-3: technologies that go inside us, e.g. pacemakers, and the future of smart foods, smart vaccines, and surgical robots.

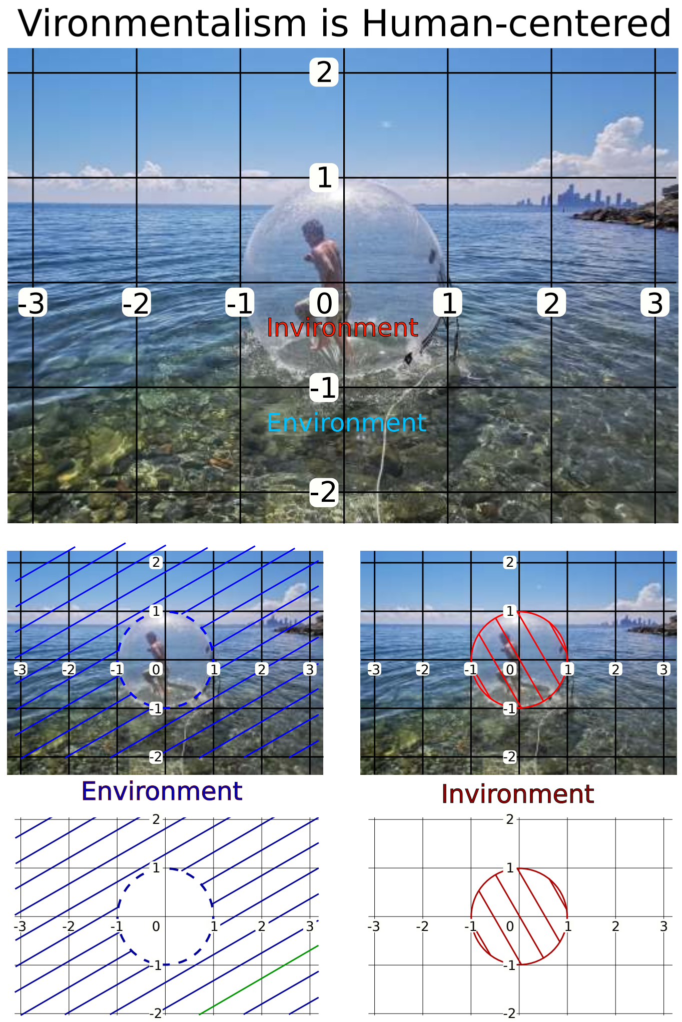


Figure 6. Consider social-distance in meters, upon a grid with spacing 1m. Here we see that a 2-metre diameter social bubble defines the Invironment. Moreover, the Vironment is shown as having a preference for being part of the Invironment, rather than the Environment, i.e. the circle is not included in the set at left, and is included in the set at right. Thus we prefer to regard the vessel as part of us rather than a part of the environment.

There are three technical terms [16], one for each of these three categories: surveillance (HC-1), sousveillance (HC-2), and uberveillance (HC-3). Human-sensing technologies that surround us are referred to as surveillant technologies, whereas human-sensing technologies that are part of us (wearables, etc.) are referred to as sousveillant technologies. Technologies that go inside us are referred to as uberveillant technologies [16–19]. Examples:
HC-1 Human monitored by establishment, e.g. interactive art installation with surveillance cameras and desktop computers;
HC-2 Human enters a vessel, e.g smart clothes, smart eyeglass, smart boat, etc;

Figure 7. HEADome™ sculpture first exhibited at LVAC (List Visual Arts Centre), October 7, 1997, 24 years ago (perhaps slightly ahead of it's time) blends into everyday street life today.

HC-3 Vessel enters a human, e.g. injectable vessel for chip implant, or ingestible sensors housed in pills.

The foregoing is summarized in the following table:

Water-Human	Activity	Description
WH-1	Fish/Sunbathe...	Human around Water
WH-2	Swim/Dip...	Human into Water
WH-3	Drink	Water into Human
Water-Tech.	Hydroactivity	–
WC-1	Smart Beaches	Tech. around Water
WC-2	Smart Plumbing	Water into Tech.
WC-3	Mersivity	Tech. into Water
Human-Tech.	Veillance	–
HC-1	Surveillance	Tech. around Human
HC-2	Sousveillance	Tech. onto Human
HC-3	Uberveillance	Tech. into Human

In addition to considering the boundary or interface between humans, water, and technology, we can also consider the physical scale (e.g. from small to large) at which this interaction takes place. A small vessel like a windsurfer feels like it is part of our body, as compared to a large yacht or ship with multiple crew members. See Fig 9.

Additionally we can consider the computational scale (the bottom-to-top axis), e.g. distributed data ("little data") such as blockchain versus centralized data ("big data").

Finally, we consider the sociopolitical scale, i.e. surveillance ("big watching") as compared with sousveillance ("little watching").

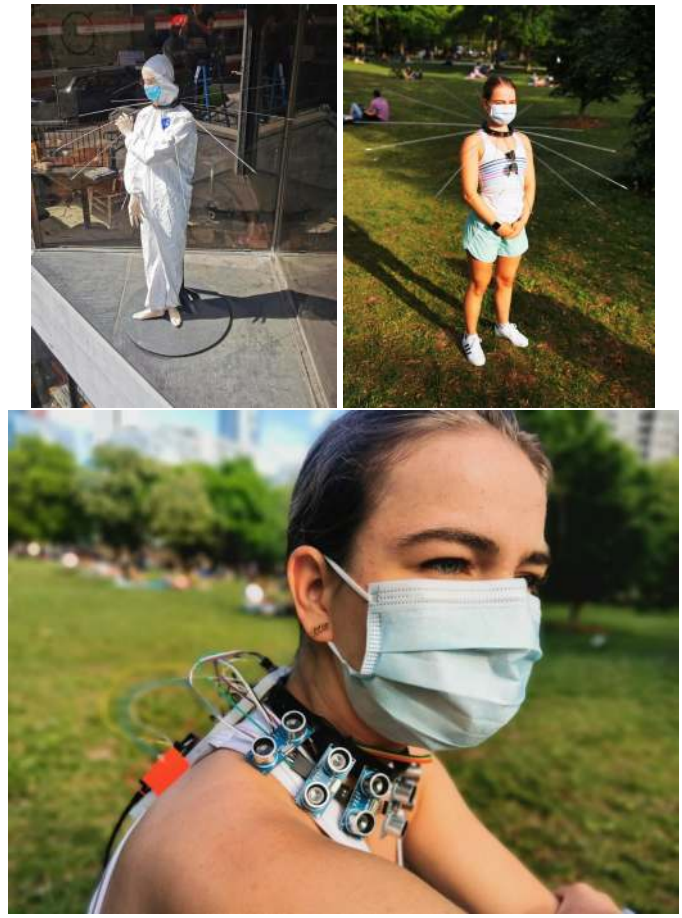


Figure 8. Social-Distancer™ art installation at DECONism Gallery for DECONference 2020 in collaboration with the Marshall McLuhan Centre for Culture and Technology. A more practical version was built as a necklace from 12 sonar devices arranged in a clock-like pattern to warn the wearer of the direction of approach of social-distance violators [13].

1.8. Water-Human-Computer Interaction

The central intersection of the circles ("Waterborg", Fig 3) introduces exciting new possibilities at the intersection of human, water, and technology/computing.

1.8.1 Health

HC-2 and HC-3 technologies may come together with WH-2 and WH-3 technologies to improve mental and physical health. Wearables and implantables (HC-2, HC-3 interfaces) may sense our physical health and suggest ideal times for us to go for a swim, or sense our mental health and suggest ideal times to perform cold water therapy. Wearables can continuously sense our hydration, detect when we drink water and how much we drink, and tell us when to take a drink, and how much we should drink. This system could learn a multi-modal measure of our hydration, and select the ideal water ingestion program for mental, heart, digestion, skin, and hair health. The system could also include wearables that wirelessly sense the hydration of other people that the user is with and let others know if they are severely dehydrated.

This can be expanded to an unconscious user interface using

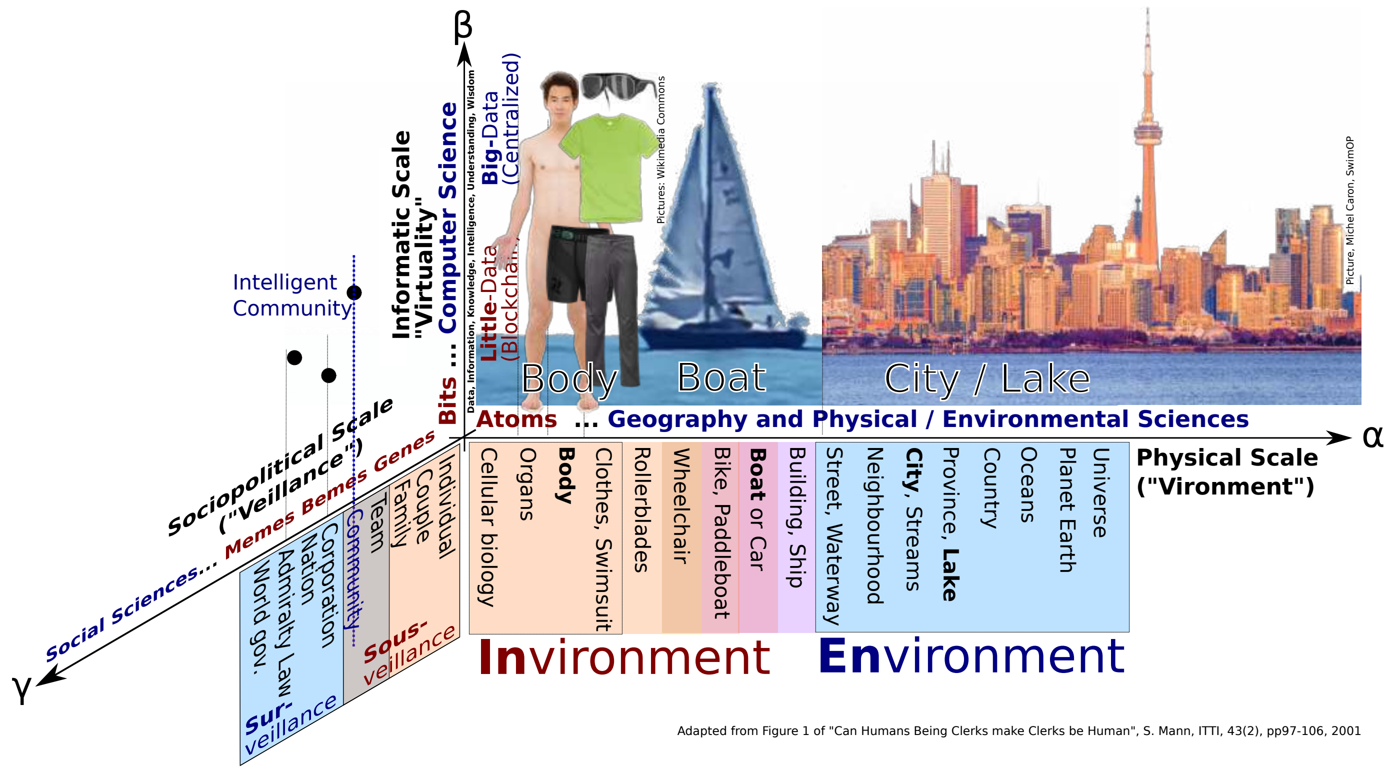


Figure 9. Scalespace taxonomy / graph. The axis from left to right denotes physical scale from atoms (and subatomic particles) at the origin, to cells, body organs, the whole body, and then to clothes, and then to small vessels, and finally to cities, countries, oceans, and finally the whole universe. Note the progression along this axis from Body, to Boat, to City/Lake, etc. We may also consider the computational scale (e.g. "little data" versus "big data"), and the sociopolitical scale along human/organizational dimensions. At the outer extreme of these β and γ axes we have "The Bigs", e.g. Big Data (centralized data collection), Big Watching (surveillance) $\approx$ "Big Brother", Big Pharma, Big Science, Big Banks, etc., whereas closer to the origin we have distributed data (blockchain), "little watching" (sousveillance), etc.. Figure adapted from [20].

water tubes with direct input to our digestion system in a feedback loop with wearable hydration sensors, the system could maintain an ideal level of user hydration with no conscious input or action required by the user. This would remove the need for users to constantly devote time and attention to tracking their water intake, fetching more water, stopping what they are doing in order to drink, etc.

1.8.2 Sustainability

We'll have zero-waste sustainable living systems that sense the precise amount of water that every individual needs (according to factors such as height, weight, physical activity, etc.), along with wearable (e.g. backpack) technology that can accept water in any form of dirtiness and output clean potable water for drinking, washing, etc. Everyone will have a basic human right to receive a fair quantity of water, the quantity of which is the amount needed for hydration, bathing, cleaning, etc. Used/waste water will be automatically collected, cleaned, and redeposited into the individual's personal water supply. This will encourage sustainability and allow everyone to receive the water they need.

Taken to the limit, this technology could allow for personal, individualized water cycles, e.g. our allocation of water could become part of us, just like the water in our bodies is part of us, the water in our backpack would be part of us as well, e.g. we could each be self-sufficient with a camel-like water reservoir as a technological prosthesis.

1.8.3 Social WaterHCI

Imagine a "collective swimming pool" where a group of people come together and contribute their individual water allocations to "pool" their resources, into a swimming pool. They then all swim together in this shared space, where they literally take part in each others resources, in each others' "selves", water becoming a metaphor for the ego-dissolving experience of social interaction and sharing. In this exchange of "bodies" of water and human bodies, we'll see renewed respect for the sacredness and sanctity of water.

1.8.4 Extended Reality

XR can enhance the experience of swimming with augmediated (augmented and mediated) [21, 22] reality through the use of infrared (IR), thermal, HDR (High Dynamic Range), ultrasonic, etc. vision to see/sense/experience near-water and underwater environments from a variety of vantage points. Scubadiving is already a cyborg activity, and underwater XR presents a new and extended way of experiencing this underwater recreational activity, as the biological life at floor of a body of water could be observed from an entirely new sensory space. Further, this could allow for underwater wreckage, military, and infrastructure teams to enhance human sensory capabilities during inspection.

Water is itself a user-interface medium, e.g we can use water as a haptic interface with jets of water shooting at a person to stimulate touch and physical force, or with microfluidics in haptic wearables [23], or with bone-conduction audio, etc. instantiations of fluidic user interfaces.

The XR sensory deprivation tank is another kind of interaction at the nexus of water, humans, and computers. It is a form of fluidic user-interface that has the opposite goal of most other interfaces, i.e. it prioritizes a lack of stimulation. Whereas most interfaces provide humans with more information, augmentation, media access, etc., the XR float tank is the limit of the NUI (Natural User Interface) which disappears and causes all other *external* stimulation to disappear as well.

1.8.5 Weather Therapy

In light-therapy, light is used as an affective interface [24] to guide users' to a positive affective state. Weather, too, can be used as an affective interface - the most obvious and moving aspect of weather is water, i.e. snow and rain. Water in weather can completely change our state - rain clouds in the sky covering the sun can make us depressed - sun glinting off a lake can makes us ecstatic or at peace. Water in nature can serve as a source of affective stimulation. AR/VR/XR could induce these effects by simulating and accentuating the affective aspects of weather. For example, someone with anxiety may be eased by light rain in a VR environment. An individual with SAD (seasonal affective disorder) may use AR to alter their overcast environment into a sunny day (going past just light-therapy into fully immersive weather-therapy).

1.9. Examples of grand challenges in WaterHCI

The Interface Taxonomy leads us to one of the grand challenges: Given the growing centralization of global water management, stewardship, "big data" aggregation, "big watching" (surveillance) sensing, and ever more centralized powerful international entities, how can we create a "bottom-up" (sousveillant) accountability? What we need is a technological framework for "trustless systems" (computer systems that don't require trust in large entities, equipment manufacturers, etc.). Can water/human/computer governance be made that is decentralized, distributed, and uncorruptible?

Because of the intimate and sensitive nature of many water-human-computer interactions (e.g. camera based smart toilets, automatic drowning detection in bathrooms, and the like), how can an end user verify the integrity and privacy of their personal information without having to trust large organizations? Can trust be a technological construct that can be integrated directly into the systems in a way that end users can verify it? Perhaps with blockchain sousveillance? Smart veillance contracts?

How can we ensure clean drinking water, clean swimmable water, and clean fishable waters? The work of Swim Drink Fish (Mark Mattson) is a great start here, along with the efforts of the Waterkeeper Alliance.

Given the strong environmentalist movement, how can we also balance these successful efforts with inironmentalism, e.g. free easy and fair access by individuals to our water and waterways? The Gord Edgar Downie Pier in Kingston Ontario, for example, is a great start. San Francisco also features bather entrances (stairs going down into the water) at 400m intervals along the very busy San Francisco inner harbour.

But there are still places where it is forbidden for non-cyborgs (natural humans) to go. For example, it has been said that it is forbidden to swim to Toronto Island but if a person is surrounded by a vessel, going to the island is legal. Consider a yacht with a pool onboard having a vision sensor that steers and conns the vessel in accordance with the movements of a swimmer in the onboard pool, such that the swimmer is driving the boat by swimming. Now take the limit as the vessel and pool get smaller. Consider an inflatable 1-person dinghy with the bottom cut out. This forms a pool in the dinghy that is itself the lake. Thus the dinghy is simply a swim ring that makes the swimmer into a cyborg to grant the cyborg "permission" to swim in the lake, much like we once had to dress ourselves up in a cardboard automobile costume to be served at a fast-food restaurant that was only open to drive-through customers. How much "car" do we need to be wearing to be served there?

Thus what we have here is a human-rights issue in a world the discriminates against swimmers. There must be a solution that provides safe, accessible waters to swimmers.

Is it possible (perhaps technologically) to make a safe and reliable passage for swimmers? More generally, what can be done, technologically, to facilitate safe swimming in urban settings? Consider, for example, a Stand-Up Paddleboard (SUP). It is primarily a convex object, and there is no way for a person to be inside it. Thus it is not a vessel. Yet paddleboards have recently been brought under legal rules for vessels, i.e. are legally defined as vessels so that they can be controlled by the rules normally applied to vessels. This includes mandates for having a lifejacket onboard, signaling device (whistle), etc.. But another side effect of this legal fiction is that a paddleboard (and presumably a person accompanying it) is allowed to go anywhere a vessel can go. And since one can't be inside the paddleboard, being in the water next to it is a normal and reasonable state of being (paddleboarders often fall off the board and sometimes swim along with it). This gave rise to SmartSUP, the intelligent paddleboard equipped with radar, sonar, navigation, lighting, etc., used as a towfloat to be pulled behind a swimmer. In this way a person can swim while using the paddleboard as a safety visibility marker, and also as a form of permission to be present in places where vessels are legally entitled to be. See Fig 10

How can we invent, design, and build techologies that effectively operate at the intersection of humans, water, and computing, such as to provide reliable operation. How can we reliably sense physiological information (e.g. ECG [electrocardiographic]) underwater? How can we reliably sense the brain (e.g. EEG [electroencephalogram brainwave]) underwater?

What can we do to mitigate disease transmission? Is it possible to build a self-cleaning keyboard that requires zero maintenance and can be installed in a public park?

Can we train the human body to function well in icewater, and how can icewater swims be used as a substitute for drugs and other mental health therapies?

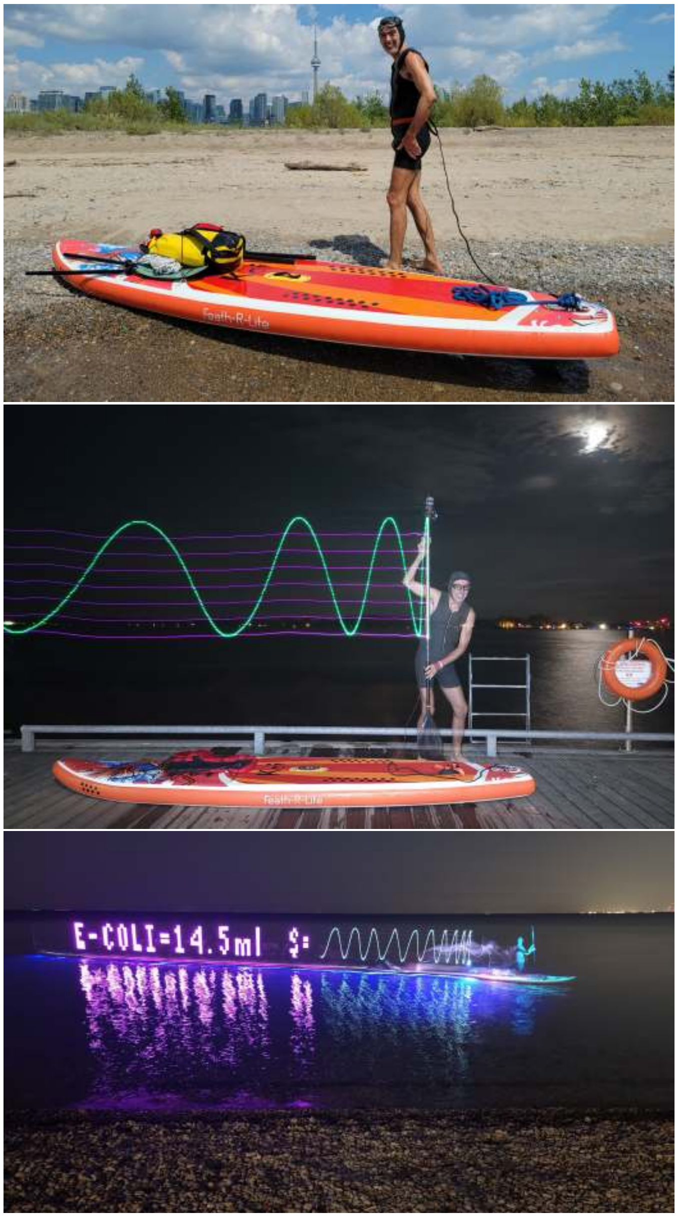


Figure 10. Safe and legal swimming in places where swimming is prohibited! For safety we have large groups of paddleboarders and swimmers using paddleboards as towfloats (note the waist strap rather than an ankle strap) for extreme visibility day or night, along with radar, sonar, computer vision, and extended reality (XR) sensing and meta-sensing across all dimensions of law, ethics, and safety. Note also the SWIM (Sequential Wave Imprinting Machine) for extended reality sensing and meta-sensing. Finally, as "cyborgs" we can legally and safely swim in urban spaces such as downtown Toronto where no swimming is allowed for non-cyborgs.

2. History of WaterHCI

2.1. Origin of WaterHCI in Ontario

> ``The legend lives on from the
> Chippewa on down, of the big lake
> they called Gitche Gumee.
> The lake, it is said, never gives
> up her dead, when the skies of
> November turn gloomy.''
>
> -- Canadian singer-songwriter
> Gordon Lightfoot, ``The Wreck of
> the Edmund Fitzgerald''

Ontario, which is Canada's most populous province, is home to the world's largest (by surface area) freshwater lake, Lake Superior, originally known by its Ojibwe name, "Gitche Gumee", meaning "Huge Water".

Superior holds 10% of the world's surface freshwater, and is part of the network of lakes known as the Great Lakes which together hold 21% of the world's freshwater (84% of North America's freshwater).

This renders Ontario of strategic importance in regards to water stewardship.

The intersection of water, humans, and computers is a growing field of research that was born in Southern Ontario in the 1960s and 1970s with the invention of the hydraulophone, H2Organ, poseidophone, underwater VR (e.g. the VR float tank), the SWIM (Sequential Wave Imprinting Machine) [25], and other water-human-machine interface technologies known as "Fluid User-Interfaces", "Natural User-Interfaces" (NUIs), Direct User-Interfaces, and Metaphor-Free Computing at the intersection of art, science, technology, theatre, music, philosophy, and social-commentary [4, 26–30].

For example, SWIM [25] is an augmented reality overlay system invented in 1974, makes radio waves, and sound waves, traveling through air, water, or solid matter visible *and* interactive. This early form of water-human-computer interaction led to many later developments, such as the chirplet transform in the 1980s and 1990s [31], which was first applied to interactive marine radar systems for water-based augmented reality.

2.2. WaterHCI in Toronto

Toronto is Canada's most populous city, and is the capital of Ontario, as well as home of Canada's largest (in terms of enrollment as well as annual research budget) university, the University of Toronto.

In 1998 WaterHCI came to University of Toronto as a collaboration between the McLuhan Program in Culture and Technology, and the Department of Electrical and Computer Engineering, culminating in a series of DECONferences exploring the interface between water, humans, and computing, in the context of pandemic preparedness, art, music, and theatre.

The DECONferences explored the societal, cultural, artistic, philosophical, scientific, theatrical, political, and technological aspects of privacy, security, human rights, and trust associated with pandemic preparedness. To do this, various new WaterHCI technologies were invented, including:

- Underwater VR (Virtual Reality) [Leonardo 37(5), p372-374, 2004] [32] (Fig. 11);
- PanopDecon, an Internet-connected panoptic column shower equipped with AI (Artifical Intelligence) body-scanning technology for pandemic preparedness. For the computer vision system in the 6-person column shower, which resulted in the creation of the world's first parallel GPU-based super-computer that used graphics processors to do computer vision. Computer vision ("turning pictures into numbers") is often referred to as the reciprocal of

computer graphics ("turning numbers into pictures"). At DECONference 2001 this system was named OpenVIDIA, predecessor of nVIDIA's CUDA [33, 34] (the lead student working on this project went on to work at nVIDIA after completing the project). An interesting discovery from the GPU-based computing in the shower facility was that the heat that it produced could be used to (partially) heat the water and the air in the shower room. Thus rather than use electric heating elements, "free" electricity was obtained from the computing. The electricity for computation is free-of-cost because it is offset by what would be required of the electric water heaters [27, 33]. See Fig 12. ;

- Blue Roofs: the use of rain water to cool photovoltaic solar panels that also heat the water for a shower that irrigates a green roof, for example. The Blue Roofs invention won first prize in the Coram International Sustainable Design Competition (10,000 Euros) [http://wearcam.org/blueroofs/];
- Other smart bathing environments equipped with computer vision for drowning detection, automation of bathroom fixtures, bathing safety, etc. [35], and
- self-cleaning keyboards and touch screens that constantly wash your hands with every keystroke or touch [4, 28].

2.3. Swim Drink Fish

Swim Drink Fish (SDF) is a non-profit organization founded 20 years ago in 2001 with a mission to safeguard and advocate for swimmable, drinkable, fishable water. An important focus of SDF is clean water: water we can swim in; water we can drink; and water we can eat fish from, i.e. water that is safe for both humans and wildlife to use and rely on.

We all support decisions that eliminate untreated sewage, stormwater and garbage waste from our swimmable drinkable fishable waters. This benefits humans, fish and birds alike.

This is why we support new access to recreational water and more public spaces and beaches that encourage connection to the water. We support better and more water quality monitoring in our waters. And we support sharing and reporting of water monitoring data to the public through timely technology platforms like the Smart Buoy which has data available in real-time on SDF's Swimguide.

We believe that water is the basis of our communities. It is fundamental to our health and wellness. It is inspiring. It is where we live and why we live there.

It is also where all our waste ends up. It is vulnerable and needs protection and restoration.

To protect water we need a movement of people working at the local level to protect it, to fight for swimmable drinkable fishable water, and to fight for the rights to access that water (e.g. Ontario Place beach, etc.).

To protect ecosystems we need to fight together for swimmable drinkable fishable water. No one can do it alone. We need a nation of water leaders.

All environmental legal victories, scientific breakthroughs, cleanup programs and restorations have the greatest impact when they are supported by a culture that remembers its bidirectional relationship with water.

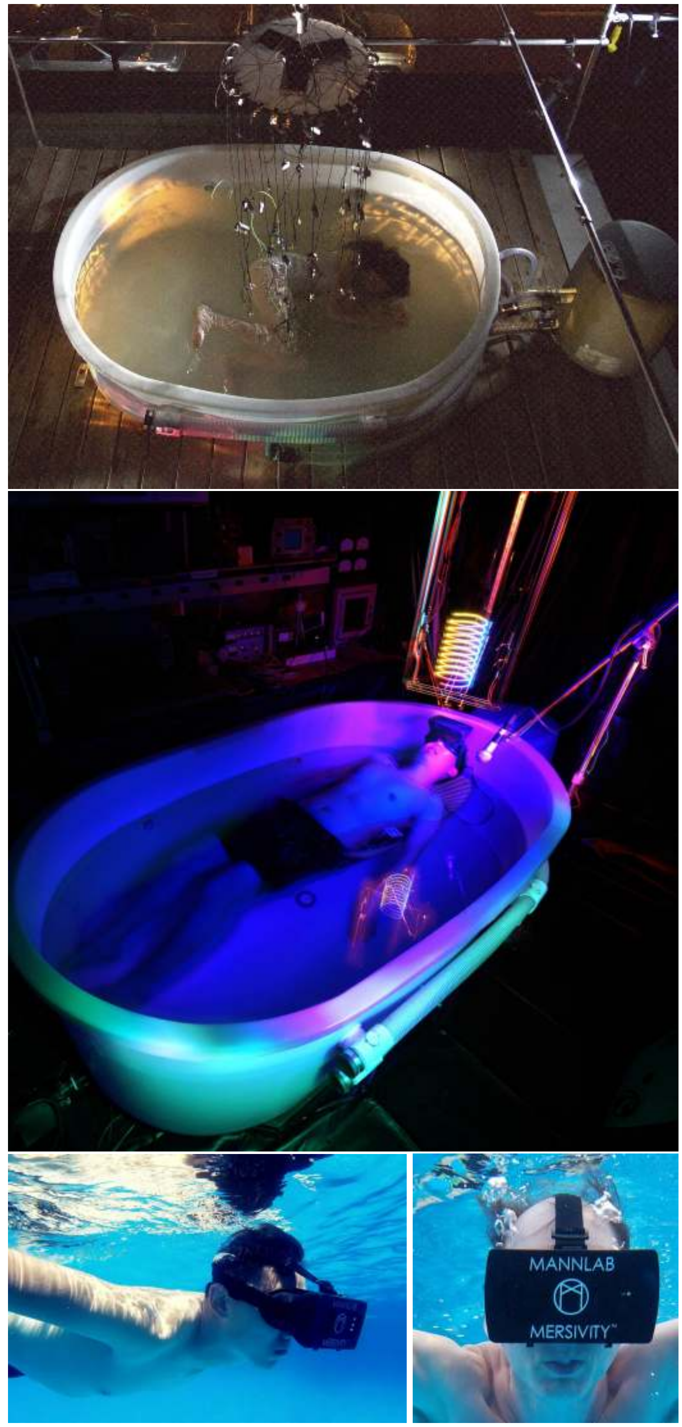


Figure 11. Early underwater VR/AR/XR (Virtual Reality / Augmented Reality / Extended Reality) sensory-deprivation float tank with BCI (Brain-Computer Interface) [32]. The translucent tub facilitated full surround-vision panoramic-projection for a fully immersive VR/AR/XR experience. Subsequently an underwater VR headset was developed for a more immersive experience together with a SWIM suspended above the tank. In larger bodies of water this creates a sense of free-floating immersive VR we call "Mersivity".

The defining characteristic of SDF's Canadian culture and our collective identity is clean water. The relationship to water was once expressed through exploration, freedom of movement passage, trade, opportunity and natural and economic wealth.

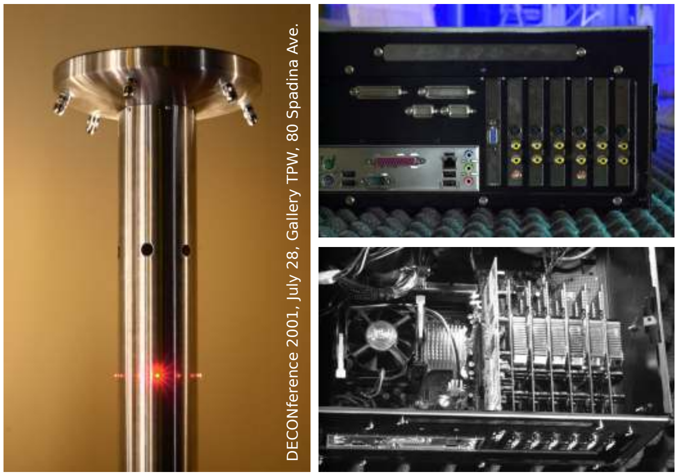


Figure 12. Panopdecon, a 6-person panoptic decontamination shower at Gallery TPW for DECONference 2001. DECONference 2001 was an exploration of art, science, technology, culture, privacy, security, and trust at the intersection of water, humans, and hands-free vision-based computer-interfaces [27]. Six depth cameras built seamlessly into the Bradley 6-person column shower were connected to the world's first GPGPU (general-purpose graphics processing unit) parallel computer system using graphics cards to perform computer vision.

Today, our cultural awareness of that relationship is fading. We seem to be forgetting how closely our fate is tied to water – and we do so at our own peril.

Our fondest memories involve water - swimming, canoeing, fishing. In Canada these memories are more popular than even hockey.

Moreover: 90% of Canadians believe kids need to spend time outdoors. Clean water and thriving ecosystems are unifying causes in Canada, like Medicare and Multiculturalism. Environmental protection is part of our moral beliefs. Canadians desire a clean and wild environment more than any country in the world.

Our challenge at SDF is to ensure our desire for clean water and the wildlife is supported but our laws and public health protections. We are working to build a movement of people working for swimmable drinkable fishable water. We are starting by connecting people to water, like at Ontario Place on Lake Ontario near Toronto's downtown core. Connection leads to protection. Swimming leads to drinkable fishable water.
Here are some useful links:

- www.theswimguide.org
- www.waterkeeper.ca
- www.Swimdrinkfish.ca
- greatlakes.guide
- watermarkproject.ca

2.4. Ontario Place

Toronto is also home of Ontario Place where downtown Toronto's only beach is located, where we have conducted water quality research, organized beach cleanups (removed sharp dangerous metal objects from the water, etc.), and built an outdoor classroom using materials salvaged from the water (Fig13).

Figure 13. Hauling dangerous sharp metal objects out of the water during our daily beach cleanups, including a rusty old railing in the water. This was used to make the outdoor classroom at Ontario Place, home of downtown Toronto's only beach.

Recently we also designed and built a smart buoy prototype [36] (Fig14) and deployed it into the Ontario Place West Channel (Fig15).

3. Water and Computing

3.1. Technology Enters Water

In regards to the Interface Taxonomy, when the technology crosses the air-water interface and enters the water, we denote this situation by way of the green (technology) circle inside the blue (water) circle.

One example of this Technology in Water is the measurement of water quality parameters using an autonomous watercraft. The watercraft is propelled using two rear air-blowing propellers. By varying the throttling ratio between the propellers, the watercraft is able to perform forward, right turn, and left turning maneuvers. The craft tugs a sensor pod capable of measuring water temperature. However, other water quality sensors can be integrated into the sensor pod. This way, the water surface temperature can be spatially resolved much more accurately compared to non-contact methods such as aerial thermography. Figures 16 and 17 show the experimental setup and experimental results of the watercraft project respectively. Paired with a tracking aerial drone, the watercraft's traversing path can be finely mapped and the spatial temperature mapping of the water can be overlaid onto the aerial photographs taken by the tracking drone.

Such a technology can deliver a significant future social good by communicating water quality parameters to people without a need for human intervention. The craft can autonomously traverse in a raster pattern, producing mappings of water quality parameters, using highly accurate and precise contact methods.

Another example of this Technology-in-Water is the Smart Buoy Project mentioned above.

Figure 14. Building the Smart Buoy prototype. We first drilled out an existing buoy and then used cord seals having the computer and radio and antenna unit inside the hollow of the buoy and the sensor hanging down into the water. One lesson learned is that most buoys have only a very small opening, yet most sensing equipment is quite large. Here the sensor was almost 3 inches at its fattest point and would not fit through a standard 2.465 inch opening, so we had to trim it down while maintaining its waterproofness. (Bottom right) pictured at our lab with some of the other artefacts of our research: hydraulophone, underwater oscilloscope, and chalkboard illustrating HeadGames™. (system for teaching hydraulic head as a function of flow.)

Figure 15. Smart Buoy deployed in Ontario Place West Channel, January 2021 [36].

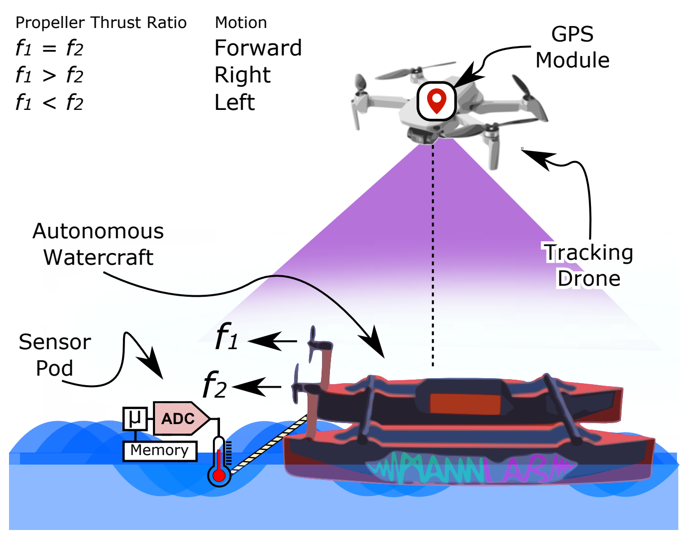


Figure 16. The experimental setup for the autonomous spatial measurement of water temperature.

3.2. Water Enters Technology: Smart Plumbing

Smart faucets, smart toilets, smart showers and baths, etc., are examples where water flows through technology such as solenoid valves, temperature sensors, etc., in order to, for example, monitor plumbing equipment. In terms of Interface Taxonomy this is denoted by the blue circle (water) inside the green circle (technology/sensing/computation).

Smart plumbing is often also used to make it respond to human interaction. In some cases the human may intersect the water (e.g. smart bath, smart shower, smart faucet) or may remain separated from the water, e.g. smart toilet, smart urinal. In some cases both modes of operation will be possible in the same fixture, e.g. a toilet that is also a bidet, so that initially the water-in-tech does not overlap the human (e.g. during deposit of waste into the bowl) but then at a later point in time (e.g. during bidet function) the human and water intersect.

To the best of our knowledge, the world's most technologically advanced example of water-in-technology is the Precision Health toilet developed at Stanford University, as shown in

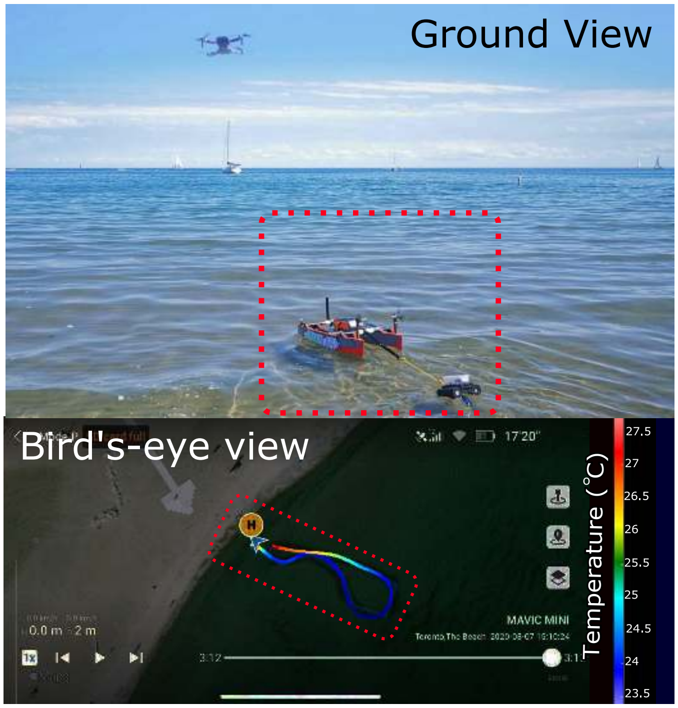


Figure 17. The spatial map of surface water temperature over the traversed path of the autonomous watercraft.

Fig 18.

4. Monitoring of humans in water

Technological monitoring of humans in water is an example in which humans are in the water (swimming, wading, bathing, showering, etc.) and are monitored by technology that is outside the water and outside the humans (e.g. a surveillance camera overlooking the water). In terms of the Interface Taxonomy, it is denoted by the red circle (human) inside the green circle (technology) separated from the blue circle (water).

AI (Artificial Intelligence) finds its way into nearly every aspect of our lives. We have surveillance and smart cities, smart buildings, smart factories, and the like. Perhaps the last place to see the adoption of smart technologies is water, e.g. natural bodies of water, beaches, etc., as well as human-made bodies of water like pools, spas, baths, and the like.

Water safety such as automated drowning detection is a relatively recent development as compared to surveillance of land-based activities. Examples include automated drowning detection or shark detection by way of surveillance cameras mounted along a beach.

We proffer a taxonomy of these and related safety technologies as shown in Fig 19.

4.1. Smart pools, waterparks, and spas

Pools and aquatic parks have increased in complexity (size, design, activities), but we have failed to keep pace with technology that could anticipate or identify an injury or submersion threat before it becomes a drowning incident.

Aquatic safety technology is technology for safety, fist aid, improved operational efficiency, e.g. both patron-facing education and enterprise-facing education, staff training, review of rescues, etc. occupancy load sensing (e.g. automatic dispensation of chemicals and control of pump based on bather load), automatic sensing of social-distancing, as well as technology like automatic face and body recognition against predatory behaviour, violence, theft, and unauthorized use of facilties.

AI has recently been applied to pools and other human-made bodies of water like spas, baths, etc., using underwater cameras, most notably, Poseidon, Davo SwimEye, LifeguardEye, Lynxight, Coral, and AngelEye.

These systems are improve safety, such as by reducing drowning deaths, injuries, or criminal activity, in public and private facilities [37–40].

4.2. Underwater pool cameras

Of these, the most advanced is the AngelEye system which uses underwater smart LED lighting, e.g. LED lighting with built in camera system, as shown in Fig 20.

4.3. Smart beaches

Similar efforts directed at natural bodies of water are much more challenging. The Smart Beaches projects are underway in Australia, Spain, Sweden, and there is also a Smart Beach project in Canada.

5. Transportation as a form of Human-Environment Interface

The containment of a human in a vehicle is another form of human-nature interface. Just as clothing or cyborg technology can mediate or augment the human experience, a vehicle is designed to expand human capabilities (e.g. in terms of speed), while protecting humans from the environment.

When a human enters into a transportation vehicle, and closes the door, the human loses some control, but gains power or agency. Losing control happens when a seatbelt is buckled, or when a door is locked shut preventing exiting (such as a positive-pressure door on a passenger jet, which can't be opened when the plane is flying at high altitude). Gaining agency occurs in the human-environment relationship by giving the human more power, acceleration, or velocity, than would be possible with a human body alone.

One extreme example is TransPod. TransPod is a high-speed transportation system designed to carry passengers at over 1000 km/h between cities. The TransPod vehicle is being developed as an aerospace vehicle that operates like a train. With electrically-powered propulsion, guidance and control, the TransPod vehicle is the size of a small passenger jet without the wings. Travelling in a protected guideway, TransPod uses reduced air pressure to reduce air resistance [41].

Safety systems are critical for the TransPod vehicle, and thus the vehicle forms a first layer of cyborg-like "clothing" around the passenger. These safety systems include fault-tolerant redundant computer control, backup electronic control systems, and failsafe mechanical systems.

There are two environment-technology interfaces in the TransPod system: The vehicle body, which must contain the stabilized environmental air pressure inside the vehicle, pushing outward toward the reduced pressure outside the vehicle.

Figure 18. Stanford University Precision Health toilet with (i) Pressure sensor, (ii) Motion sensor, (iii) Urinalysis, (iv) Stool camera to monitor for CoViD or other health issues, (v) Anus camera to provide biometric identification, and (iv) Uriflow camera. Using AI and computer vision, the toilet performs medical diagnostics for early alerting of health issues. This is a good example that highlights the need to also consider priveillance which is the interplay between privacy, surveillance (being sensed) and sousveillance (self-sensing) as outlined in Section 13.1.

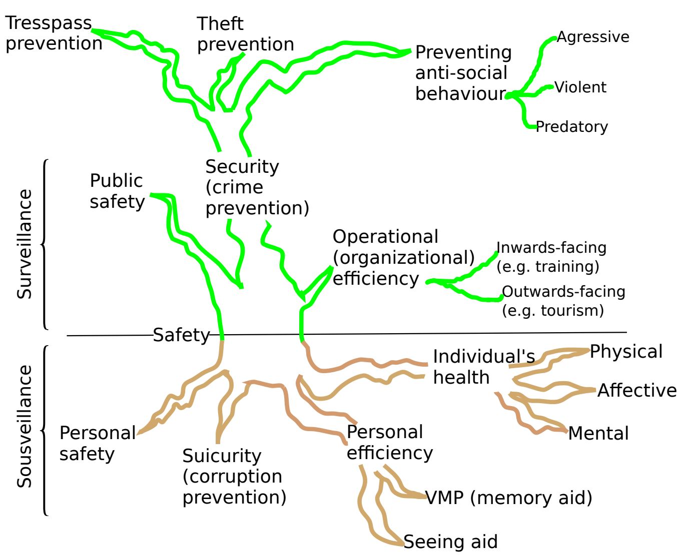


Figure 19. The "safetree" (safety tree) taxonomy, e.g. the branches and roots of safety. The trunk of the tree is all forms of safety. The branches are the elements of safety that are addressed by surveillance and the roots are the branches of safety addressed by sousveillance.

A second interface – the guideway itself, which resembles a pipe – is like an inverse of the vehicle interface, because it must contain the environmental air outside from pushing in toward reduced-pressure inside the guideway pipe. This "inverse clothing" is a second layer of nature-technology interface between the passenger, the vehicle, the guideway, and the outside world.

6. Humans in Technology in Water

6.1. Underwater Virtual Reality

In terms of Interface Taxonomy, the situation where humans are clad in technology (wearables) that are in water (e.g. "cyborg swimmers"), we have the red circle inside the green circle inside the blue circle.

Early work on underwater VR (Virtual Reality) used translucent pools with external projectors [32], but more recently underwater VR headsets have emerged. This opens up new possibilities for waterparks, and even float tanks where a whole new world of underwater reality is possible.

Underwater virtual reality has been commercialized by Ballast Technologies, Inc. through the development of virtual reality systems that are designed for use both on and within water. Examples of underwater virtual reality systems by Ballast can be viewed in Fig21.

The VRSlide system by Ballast consists of a waterproof VR headset and tracking solution that allows participants to experience virtual reality as they physically descend a waterslide. By matching the perceived virtual motion of the participant with their actual physical motion down the waterslide, VRSlide creates the impression that participants are bobbing and weaving through various fantasy scenarios.

The DIVR system by Ballast consists of a specialized VR headset that in addition to being waterproof, is designed to maintain near-neutral buoyancy when completely submerged. This allows it's comfortable use by a snorkeler or diver, enabling participants to explore virtual environments such as coral reefs, outer space, or air travel while floating in water.

DIVR+, created through a collaboration between Ballast Technologies, Inc. and water attractions company Sub Sea Systems Inc., is a haptic feedback system that takes the form of a stationary underwater vehicle that participants can hold on to while wearing a DIVR headset. By propelling water in the direction of the participant at varying speeds, turning air jets on and off, and causing the handles of the DIVR+ unit to vibrate at key moments, DIVR+ creates the impression that participants are traveling at great speed using a handheld vehicle such as an underwater scooter, a jetpack in outer space, or a hang glider.

6.2. Underwater Augmented Reality

Underwater augmented reality allows content to be overlaid on top of existing visual reality. See Fig 22.

Recently commercialization has brought us technologies like Form Swim, and the Vuzix SmartSwim that provide an overlay that is useful for safety [43], health, and leisure. See Fig 23.

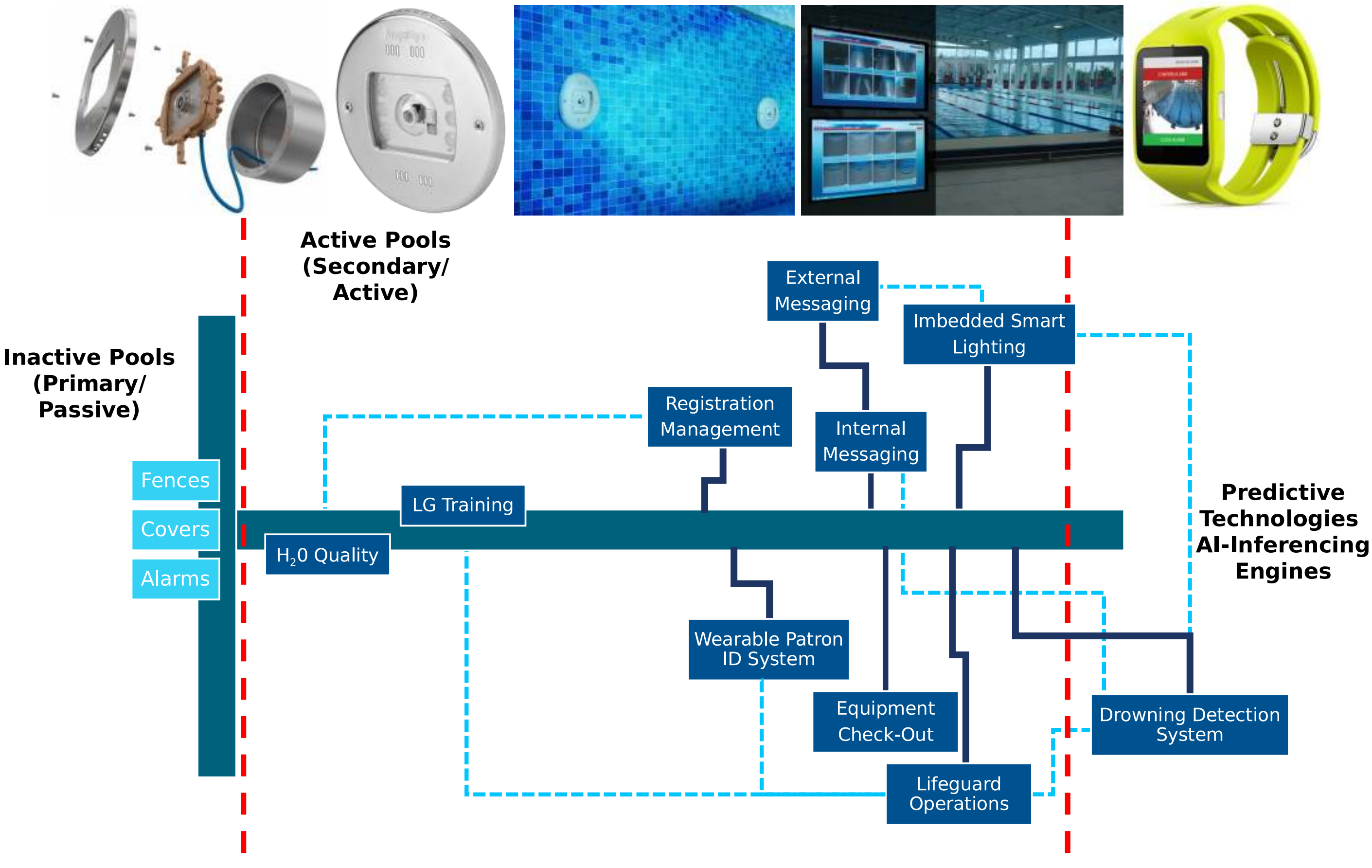


Figure 20. The AngleEye pool safety system consists of underwater and above-water cameras, feeding to a computer server with artificial intelligence for drowning detection, crime prevention, and operational safety. Alerts such as likely drownings before they happen, are sent to smartwatches worn by lifeguards.

We developed an underwater augmented reality use case that allows for self-sensing with live biometric feedback while swimming. The system uses a photoplethysmography (PPG) sensory (Polar OH1) heart rate sensor which streams data to an Android smart phone where data is collected. The Android smart phone routes live data directly to a Vuzix Smart Swim augmented reality display so users can have a live view of their heart rate as they swim.

This system is an example of humans in technology in water as the user enters water and uses technology, from within the water, to sense the effect that their interfacing with water (swimming, exposure to cold temperatures, etc.) has on their physiological state. See Fig 24 to see the functional application.

6.3. Kolympography: Drawing shapes by swimming

Finally we consider the playful art of kolympography, from the Greek words "κολύμπι" ("swimming") and "γραφιά" ("graphy"), generally meaning "drawing" or "painting". This was typically done by placing a smartphone in a towfloat to log GPS (Global Positioning System) coordinates while swimming in a particular shape or patter. Kolympography is made much easier using realtime feedback with an augmented reality display such as the Vuzix Smartswim, examples of which are shown in Fig 25.

7. Technology in humans in water

For completeness, let us consider the example of a human with a pacemaker (implantable computer that controls their heart) while swimming. In regards to Interface Taxonomy this situation is denoted as a green circle inside a red circle inside a blue circle.

8. Toys and Interaction with Water

8.1. Toys in Fluid interaction

Toys interaction sometimes stimulates our creative mind. There are many toys used in water especially for bath play and swimming. Such toys are focusing on experience using unique characteristics of water, tactile feeling and change of the shape.

Here, it is considered that there are some fluid HCI including soft robotics and stuffed toys. Uncertain tactile feeling of shape change by contact, not fixed shape, stimulates users to interact with them and to get physical feedback.

In this subsection, we describe a musical instrument using water string and a soft stuffed-toy music interaction [44].

8.2. Tangible Sound using Flowing Water String

Tangible Sound [45] is a musical instrument in which humans interact with water and the water is mediated by technol-

Figure 21. Underwater virtual reality system by Ballast.

ogy. The concept of Tangible sound is to connect the sense of touch and music, expressing their change by time.

In terms of the Interface Taxonomy shown in Fig. 3 this is indicated by an overlap between the red circle (human) and the blue circle (water) as well as an overlap between the blue circle (water) and the green circle (computer/technology).

There were various natural musical instruments such as Suikin-kutsu [1] and Shishi-odoshi [2], that are using water flow. In these instruments, natural, uncontrollable elements produce sound, but digital music and toys lose sight of such uncontrol-

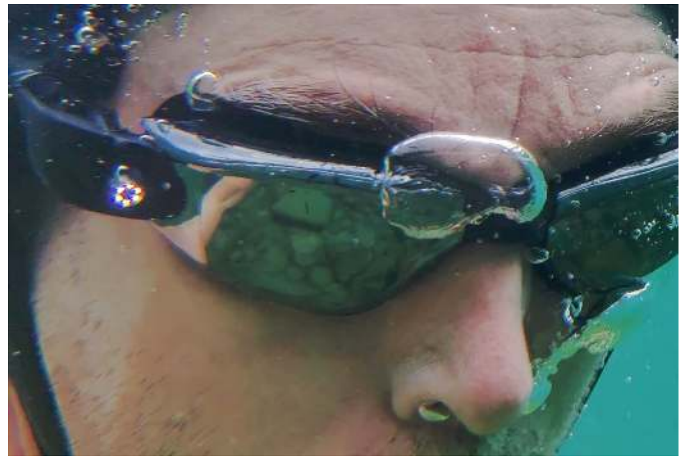


Figure 22. Custom-made underwater augmented reality eyeglass with wearable camera, underwater brain-sensor (Blueberry X Technologies brain sensing pod), and augmented reality display [42].

Figure 23. Vuzix Smart Swim underwater augmented reality system capable of displaying maps, wayfinding, etc., as well as live video feed from overhead drone for the SafeSwim [43] project.

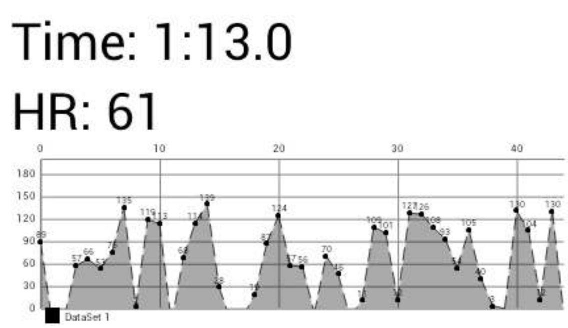


Figure 24. Vuzix Smart Swim underwater augmented reality (AR) system streaming physiological data from wearable biosensors to a live AR display.

lable elements that make sound interactions interesting. Considering these characteristics, water as a medium was applied to musical performance in Tangible Sound.

In Tangible Sound system, the water string from a faucet and a drain is created and controlled by the user. The faucet was adopted as the source controlling interface because it is a familiar and intuitive device. The amounts of water under the faucet and at the drain were measured by electrical resistance between two nichrome wires for each. The values and the difference between them were used for detecting user's input on

[1] https://en.wikipedia.org/wiki/Suikinkutsu
[2] https://en.wikipedia.org/wiki/Shishi-odoshi

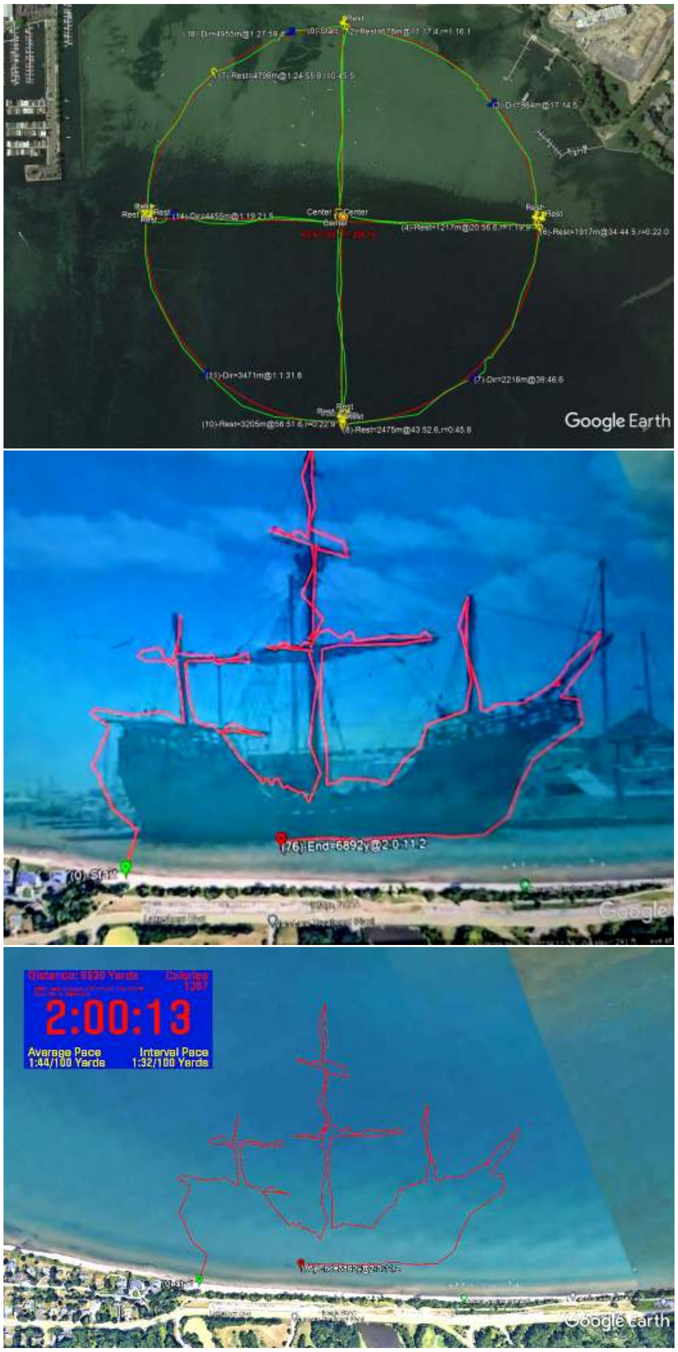


Figure 25. Examples of Kolympography, the art of drawing shapes by swimming, for Teth Day (June 28th) to draw the shape of the Phoenician letter Teth which means "wheel" (i.e. a full circle which is the quantity 2π), and also to draw the shape of a pirate ship which was done during very rough weather swimming. Swim distances: 4955 m for the drawing of the letter teth, and 6930 yards ≈ 6.3km ≈ 4 miles for the drawing of the pirate ship.

the water flow (touch, stop, and turn over the water in her/his palms). Fig 26 shows Tangible Sound system using two water tanks to create water flow from upper to lower tank.

There were four drains using funnels to detect scattered water drops by user's interaction. The main drain was set at the tallest position to get the main flow and the sub-drains were set around the main drain. Each drain makes notes in different scales so that the mixed sound created from larger numbers of drains makes dissonant notes.

Figure 26. View of Tangible Sound [45]

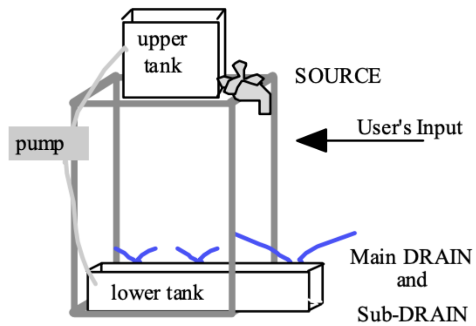


Figure 27. Tangible Sound System [45]

The perception of the soft materials such as liquid or gas can bring various new imagination and experience to not only children but also us. The digital music can draw the user's emotion and make perception of the experience strong.

Thus Tangible Sound is expected to create a novel experience of perceptual fusion between tactile feeling and sound changed by time. At the same time, the novel music experience is expected as results of controllable and uncontrollable music outputs by changing the amount of water from the faucet and by interfering with the flow of water by touching it with the user's hands, that brings feeling of natural, unstable, uncertain factor.

8.3. Interaction with Fluid Body and Mind

A context-aware sensor doll [46] was proposed to create emotional music feedback in a nonverbal communication while the soft stuffed toy can sense various physical interactions with the user. To detect various user's action on the doll, it has bending sensors built in its arms/legs, a proximity sensor, a camera and a microphone built in its head, a heat sensor and an acceleration sensor built in its abdomen. This work includes the aspects of soft and flexible tactile interaction and flexible and uncontrollable emotional states of the doll corresponding to the tactile interaction. The soft stuffed toy has an elastic reaction

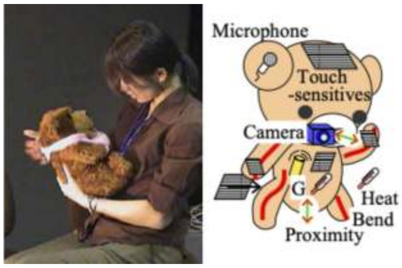


Figure 28. Structure of Context-aware Sensor Doll [44, 46, 47]

force corresponding to the user's touch with changing its shape, and that is considered a kind of fluid interaction.

The doll has its embedded character and changes its own internal states corresponding to the treatment of the user. The user cannot perfectly control the reactive music sound, that is very similar to the controllability of Tangible Sound. Moreover, its own emotional reactions make the user to change next action to the doll, so it is considered as a kind of human-agent interaction.

Here, as another flexibility of the stuffed toy, the stuffed toy itself can play not only a role of avatar (alternative) of the user to express or to speak for the user to the other person but also a role of the conversation partner. The context-aware sensor doll adopted the above flexibility with expressing music to build a musical communication in parallel with conversation.

The evaluation of the proposed tactile and musical doll in human-human conversation [47] resulted the music created by a speaker did not disturb the conversation with other person compared to the sound of continuously changing frequency.

8.4. Effect of Music Interaction with Fluid Toys

The animals and humans have water in our body, not only interacting with water on the outside. Water is the most special fluid to make humans to give uncertain feelings of the outside world and the own body. Tactile music interaction using water/fluid toys is expected to generate our fundamental and primitive bodily sense and emotion simultaneously.

9. Underwater Extended Reality: SWIM (Sequential Wave Imprinting Machine)

SWIM (Sequential Wave Imprinting Machine) was invented in 1974 for seeing otherwise invisible phenomena such as sound waves in air, water, or solids. In terms of WaterHCI the human user may be underwater or above the water (i.e. observing it and interacting with it from in the water or outside the water). Thus in terms of Interface Taxonomy it is represented by the green circle (technology) inside the blue circle (water), although it can operate also with the sensor underwater and the SWIM above the surface, as in the smart paddleboard of Fig10.

Early SWIM was moved through air or water by hand, e.g. Fluid-User-Interface™ or WaterHCI™ (Water-Human-Computer-Interface/Interaction/Intersection), or along solid matter to show sound-wave propagation in solids or seeing soundwaves recorded on magnetic tape or records, hydraulophone disks, Hammond tonewheels, etc. (rotary SWIM). SWIMbot™ was a SWIM sliding along a rail, even while used to sense phenomena not in the rail (e.g. phenomena in water, air, or vacuum), such as sound waves propagation [48]. SWIM has an early association with underwater musical instruments (hydraulophones). The nexus of water, humans, and computers allowed us to see water quality by acoustics (SWIM towed through water presenting results on an underwater XR headset). Thus there are 3 main classes of SWIM: free (e.g. hand-held); partially constrained (rail, boat, raft, towfloat, etc.); and robotic.

Figure 29. Hydraulophonic testing of water quality using the SWIM (Sequential Wave Imprinting Machine)

9.1. History of SWIM

SWIM was invented in 1974 as an immersive visualization tool to see, understand and photograph otherwise invisible phenomena such as radio wave propagation, sound wave propagation, sensing, and meta-sensing (the sensing of sensors and sensing their capacity to sense) [25, 48, 49]. SWIM has a history of applications in acoustics. See Figure 30.

Figure 31 shows a version of SWIM operating in water.

There are many ways to visualize the SWIM signature, some include HandHeld SWIMs [49], Robotic SWIMs [48] and even Drone-based SWIMs [50]. To measure water quality using sound wave propagation we developed a stand up paddleboard SWIM, as shown in Fig 10. This iteration of SWIM allowed

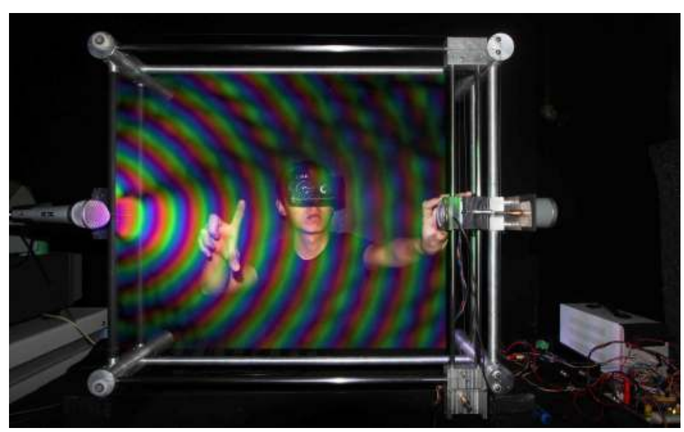


Figure 30. Photograph of SWIM showing its ability to make visible the otherwise invisible capacity of a microphone to sense. A loudspeaker attached to an RGB (Red, Green, Blue) LED (Light Emitting Diode) is moved through space by hand or robotically while the signal fed to the speaker is the reference input to a lock-in amplifier who's signal input is from the fixed (not moving) microphone. The LED is driven by the complex-valued output of the amplifier. Figure reproduced from [48]

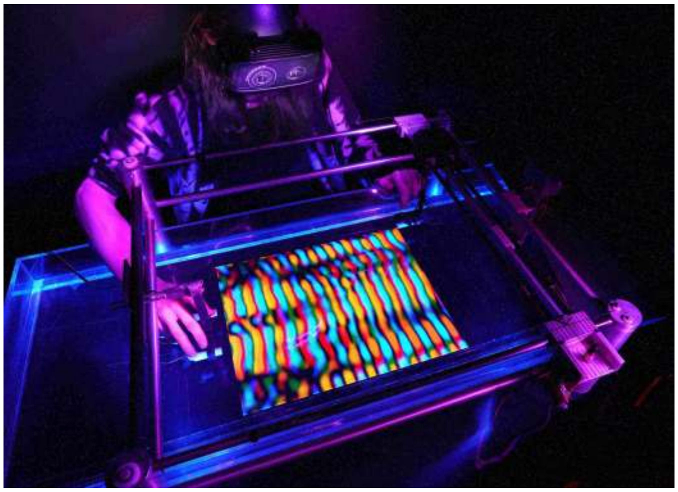


Figure 31. We demonstrate SWIM's ability to phase coherently illustrate acoustic patterns as they travel through the aquatic medium. This provides a foundation for the analysis of aquatic based acoustic sensing, a fundamental achievement on the route to creating the Aquastic-CNN pipeline.

us to sense, visualize, and understand sound wave propagation through water. SWIM is also used to provide augmented reality overlays with axis labels, tick marks, etc..

9.2. Acoustics

The study of acoustics follows from the understanding of vibrational patterns as they propagate through a medium [51]. A key signature of the acoustic wave is the medium through which it travels [52]. The wave pattern that can be visualized from acoustic propagation therefore contains encoded information about the medium it travels through. Recent studies have examined how single and multi-species colloidal type substances can effect the wave propagation signature differently and how their effect varies with the relative concentrations. Since the sampled water can contain multiple species, SWIM can be used to visualize the acoustic signatures from samples of water and thus design a illustrative construct of the sound wave propagation in the medium. Using SWIM to visualize the signal, we introduced the computational SWIM which is constructed by plotting sound wave signature into an encoded image for further use in analysis.

9.3. Module 1: Experimental Setup

The experimental setup encompasses the entire process from setting up the experiment to the collection of data. The purpose of this module is to collect sound wave propagation data from the sample and create the SWIM Plots. We begin with the theoretical experimental design and transition to the lab and field test environments, and finally the generation of SWIM Plots

9.3.1 Experimental Hardware Design

Lock-in sensing methods are among the most widely available tools in today's scientific labs. In the broadest sense, they're used to measure the amplitude and the phase of an oscillating electrical signal. Another term for lock-in detection is phase coherent sensing since both amplitude and phase of the desired signal can be measured. Lock-in detection comes in handy when the desired signal is very small in amplitude and buried under unwanted noise. An oscilloscope can measure large signals; however, when measuring small signals, the lock-in amplifier makes a difference as it combines techniques from the time and frequency domain analysis. In a quadrature lock-in amplifier, an incoming signal is pre-amplified and fed into two signal mixers. The mixers also receive a reference signal as an input. The reference signal is a pure tone sinusoid that oscillates at the frequency of the signal of interest in the incoming signal. The mixers multiply the reference and the incoming signal. One mixer receives the reference signal without a phase shift. The second mixer receives the reference signal but phase-shifted 90 degrees. The output of the two mixers is then fed into two independent low pass filters. The output of the low-pass filters forms the real and imaginary outputs of the lock-in amplifier (in Fourier terms). Some lock-in amplifier models allow for the expression of the output in the magnitude and phase format. The magnitude output is the Pythagorean sum of the real and imaginary outputs. The phase is the inverse tangent of the ratio between the imaginary and real components. The SR530 lock-in amplifier by Stanford Research is a widely used unit that allows for the fine-tuning of the lock-in parameters, namely the pre-amplifier gain, low-pass filter cut-off frequency (set by adjusting the time constant), and output format (real/imaginary versus magnitude/phase).

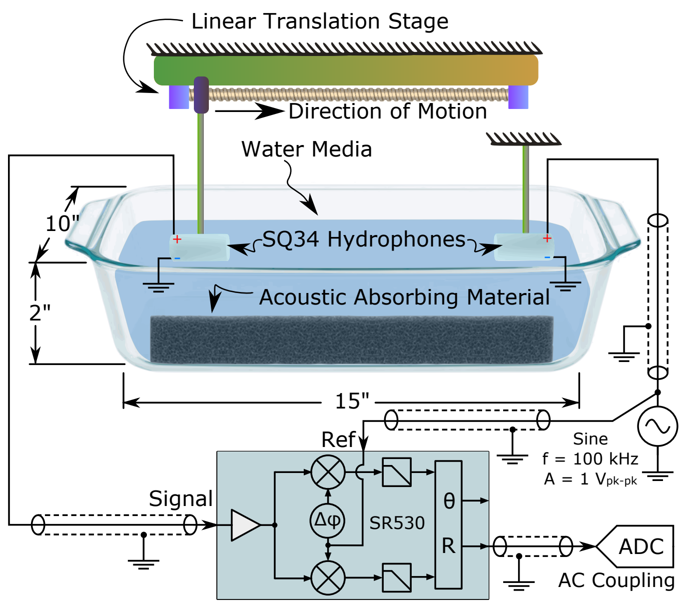


Figure 32. Visualizes the experimental setup described herein. The overall concept is the measurement of sound wave propagation through the medium using two hydrophones, one fixed, the other movable, and a Lock-In Amplifier. The translation stage moves one hydrophone toward the other with constant speed and the wave propagation was measured with the help of a lock-in amplifier.

We introduce the experimental setup in Figure 32. The experimental setup consisted of a testing vessel and two SQ34 hydrophones submerged in the water media under test. The bottom of the testing vessel was lined with acoustic absorbing foam to prevent excessive acoustic reflections. One hydrophone was fixed in place and configured as a transmitter (excited at 100 kHz). The other hydrophone was mounted to a linear actuator that moved in line with the fixed transducer. The actuated hydrophone was configured as a receiver, connected to the input signal port of the SR530 lock-in amplifier. The signal used to excite the fixed hydrophone was fed into the reference signal port of the lock-in amplifier. All electrical connections in the setup were done coaxially. The pre-amplifier gain and time constant were set to 200 and 1 second respectively. The output of the lock-in amplifier was set to magnitude/phase. The phase was ignored and the magnitude output was fed (AC coupled) into a digital storage oscilloscope capable of wave capture. For each trial, the actuated hydrophone approached the fixed hydrophone (to a point of contact) at a constant speed (10 cm travel distance), while the oscilloscope recorded the voltage output of the magnitude port of the lock-in amplifier. Various water samples were loaded into the testing vessel using siphoning and three trials were collected for each sample. See Figure 33 for a visual of the lab and field test environments.

Figure 33. Experimental setup with lock-in amplifier, hydrophones, and SUP (Stand-Up Paddleboard).

9.4. Rotary SWIM for underwater use

The use of SWIM for measurements of and in water demands hydrodynamics competitive with the aerodynamics of air-operated SWIMs. With a thousand times more drag, the water interface area of SWIMs must be reduced by the equivalent amount. In the case of Moveillance – SWIMs used for imprinting invisible motor electromagnetic fields – this is especially important since the SWIM will be driven through the water by the motor under inspection. We may consider for example collecting the SWIM pattern of a motor that drives a propeller through a gearbox. A SWIM attached to the motor directly for direct observation (for example, to avoid contamination by backlash and mechanical elasticity) must minimize its parasitic drag and thrust.

By compressing a linear SWIM to a single LED, the motor SWIM of Fig. 34 offers distinct improvements in liquid environments while preserving bandwidth of the optical analog communication. A pixelwise mapping of LED intensity to radius is overlaid on the original image, in a manner not unlike glare artefacts that lengthen with the intensity of the light source.

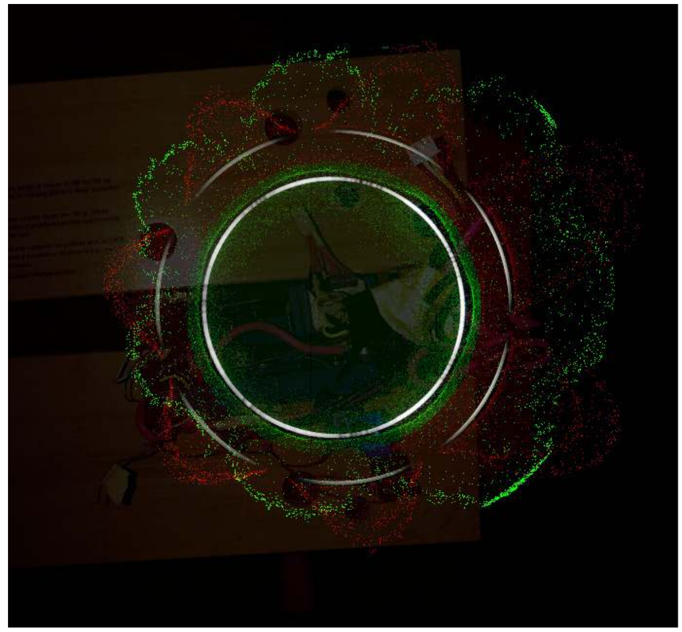
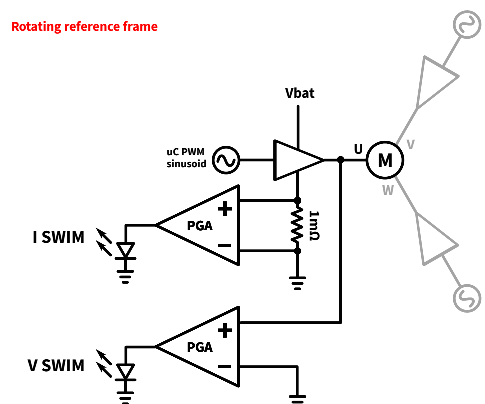
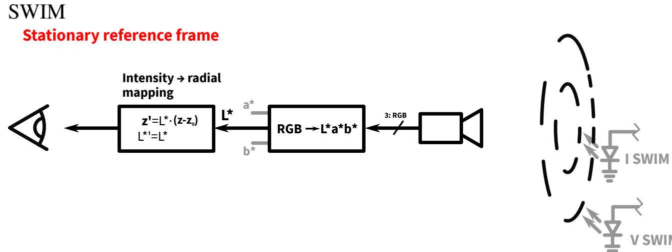


Figure 34. Long exposure photograph of single-LED motor SWIM with software SWIM expansion via intensity to radial mapping. Green (inner): current SWIM; Red (outer): voltage SWIM.



(a) Standard motor SWIM, except with single-LED output instead of linear SWIM



(b) SWIM expansion via intensity to radial pixel mapping

Figure 35. Experimental setup with motor, single-LED SWIM and software SWIM expansion for drag-sensitive analog communication

10. Industrial design for WaterHCI

In regards to industrial design, “wearables” and “water” create new challenges and opportunities. One such challenge is the design of a heart monitor that works well in water. In this context we’ve set out to design the world’s most advanced heart monitor consisting of a full 12-lead ECG (ElectroCardioGram) combined with wearable realtime ultrasound, and situational

Figure 36. World's most advanced underwater heart monitor and augmented reality biofeedback system for swimmers (Left) prototype (thanks to Dan Bowman for picture). (Right) Design of the world's most advanced heart monitor with full 12-lead ECG plus realtime wearable ultrasound, and a camera that can "see" into the water while swimming. The vision system uses AI and machine learning to anticipate activities and estimate expected heart activity based on surroundings, and automatically flag any anomalous cardiac activity.

awareness (it even has a built-in camera to see into the water while swimming!).

We recognize the importance of industrial design to WaterHCI, and we call upon industrial designers to address some of our grand challenges toward raising awareness of the importance of water at the intersection of water, humans, and computing.

11. Water, humans, computers, and cities

This paper is about taxonomies and ontologies of humans, water, and computing, within urban or natural environments. The importance of cities and WaterHCI is foremost, and we must therefore consider also the ontologies of cities and how they interact with water, humans, and computation [53].

Application level city concepts are those whose instances are produced by a single service, but they are used by other city services. Numerous vocabularies and ontologies have been created for services such as water, energy, transportation, shelters, social services, etc. For example, a detailed survey and analysis of Transportation Planning ontologies can be found in. The iCity transportation planning ontology contains over 15 ontologies spanning Households, Transportation Networks, Vehicles, Parking, Trips, Travel costs, etc. [55]. See http://ontology.eil.utoronto.ca/#icity for the complete suite of ontologies.

There is a myriad of concepts that have been proposed for the many services, at many levels of abstraction. No systematic analysis has been performed to determine which concepts belong to the domain versus application level. Nor has much been done in formalizing their definitions. Thus one of the grand challenges is to expand our Interface Taxonomy in an urban context to connect with other concepts such as sousveillant cities and media.

katsumi2018ontologies, katsumi2019ontology,

12. Mathematical foundation for WaterHCI

The time-integral of displacement (termed "absement") is a fundamental kinematic quantity in nature, and was first reported in the context of fluidic user interfaces, and in some sense forms their mathematical foundation.

Concepts such as velocity, acceleration, jerk, jounce, and so on, are well-known as the time-derivatives of displacement.

The time-*integral* of displacement, termed "absement", was first defined in 2006 [56] where the term "absement" was also coined, and absement has since been used as a new paradigm for modelling electric circuits [57]. Absement was first used [56] to describe the action of fluid flow in musical instruments, including the newly-invented hydraulophone, which generates vibrations in matter in the liquid state. The reservoir-type hydraulophone was proposed [56] to be responsive to the absement of the player's finger, unlike, for example, a piano, which is velocity-sensitive.

We now document what we believe to be the first-ever experimental measurements of absement. Here we present preliminary results of those first-ever experiments.

The methodology involved developing an experimental apparatus consisting of a fluid reservoir with a computer-controlled linear valve whose motion resulted in the precisely controlled release of fluid at continuously-varying, preprogrammed rates. Comparing the experimental measurements to a theoretical prediction of absement, a strong correlation was observed. This suggests that absement was indeed observed.

EXPERIMENT, MOTIVATION AND METHODS:
It is well understood that velocity and acceleration are calculated by taking derivatives of displacement. Similarly, absement can be mathematically calculated using integration. However, the integral of displacement has never previously been directly experimentally measured in a physical system. In order to accomplish such a measurement, an apparatus was designed and built, as shown in Fig37, using fluid dynamics to measure the time-integral of displacement directly. This apparatus uses a linear valve to separate an input fluid reservoir from a collection vessel, as shown in Fig37b. This device is designed to show absement directly as a water level in the collection vessel.

An experiment was performed using a computer controlled linear actuator, moving in motion profiles to open and close across a gap along the bottom of the valve. The fluid input reservoir was filled with water and its level (and thus head pressure) was maintained at a constant level within $\pm 2\%$ during the experiment. The fluid released through the moving valve, from the input reservoir into the collection vessel, was observed using a digital video camera. By observing the video frames, the fluid depth was measured over time. Then, a graph was made, relating the physical measurements to the theoretical value of absement calculated from the time-integral of the displacement of the valve.

The valve was programmed to move in two different velocity profiles: a trapezoidal velocity profile, and a triangular velocity profile. The experiments were repeated 5 times each. The averaged results are shown in Fig38a as measured water height.

RESULTS & DISCUSSION:

To determine the calculated absement, the known velocity of

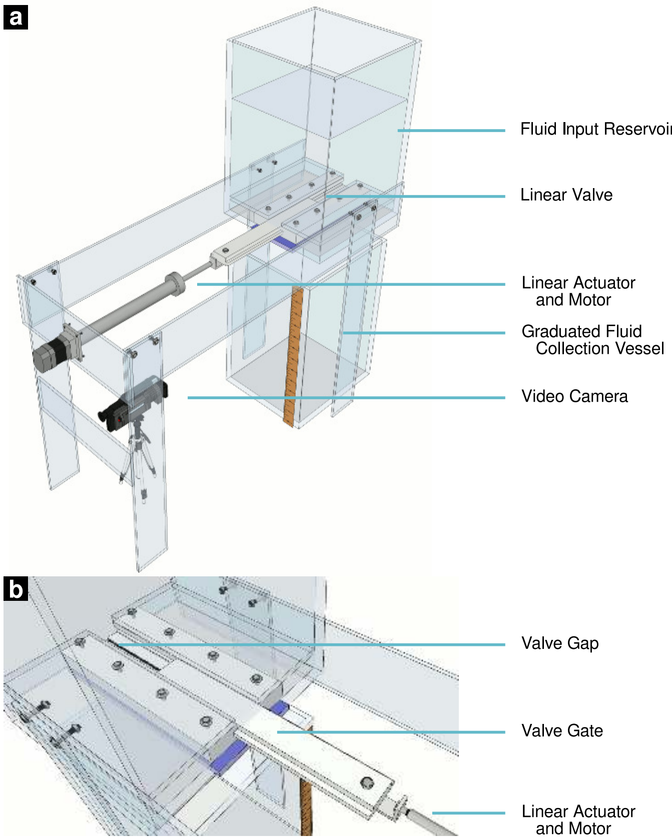


Figure 37. Absement was measured using an apparatus based on water flow. A valve was moved by a linear actuator, programmed to move at specific velocity profiles. This caused a release of water from a fluid input reservoir into a graduated fluid collection vessel. (b) Closer view of the linear valve.

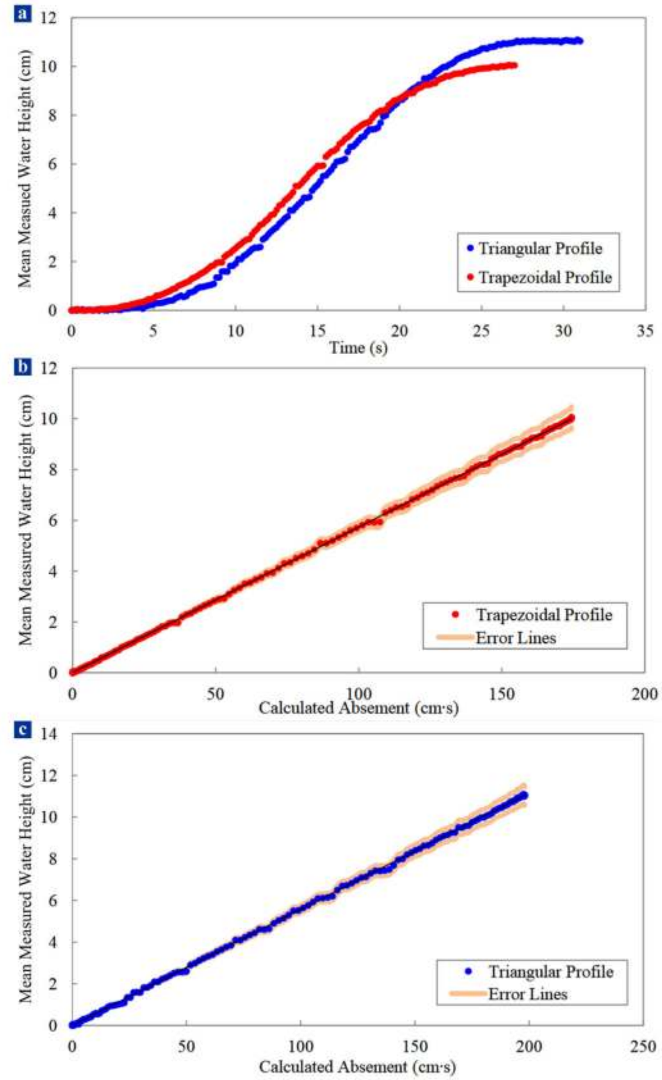


Figure 38. (a) The mean water depth measured in the collection vessel as a function of time for each motion profile. The theoretical v.s. experimental values of absement are graphed in (b) and (c), where we observe a clear relationship. Measurement uncertainties are shown on (b) and (c).

the gate was integrated twice to yield the theoretical absement versus time.

The resulting correlation can be seen in Fig38b and c, for the trapezoidal and triangular motion profiles, respectively.

Regression analysis of the data from trapezoidal and triangular motion of the linear valve, gave an $R^2 = 0.9998$ and $R^2 = 0.9997$, respectively. We observe a close correlation between the the measured volume and the mathematically calculated absement. This reveals that the experimental apparatus exhibits an absement-sensitive behavior.

This suggests that we have observed absement directly in a physical system. These experiments represent the first scientific demonstration of the time-integral of displacement.

This work, originating from the field of WaterHCI and fluidic-user-interfaces, has applications in many other disciplines.

13. Social issues: Humans, Water, and Technology

Thus far we have provided a taxonomy of technology, along with scientific and mathematical foundations, and the like. However an important dimension of WaterHCI is the societal dimension as alluded to in Section 2.2.

Two key issues that are unique to water and technology are: (1) priveillance which is the interplay between privacy, and veillance (sensing), and (2) fairness, e.g. fair and equitable distribution of water. Let us first address priveillance:

13.1. Privacy, Surveillance, and Sousveillance

Equiveillance is the interplay or balance between surveillance and sousveillance, i.e. between the surveillance cameras you might find at a beach or pool, and the wearable cameras that swimmers use for their own safety + wayfinding + navigation, etc.. These two veillance, sur-and-sous-veillance, interplay with privacy to give us priveillance, as shown in Fig 39. One of the grant challenges is how do we protect privacy, especially in places where people naked or at least partially undressed (e.g. beaches, pools, communal bathing establishments, etc.) while at the same time allowing for AI (Artificial Intelligence) of both smart environments (e.g. "smart buildings", "smart beaches", etc.) and smart inveironments ("smart people")? How can a distributed blockchain-based personal safety+securuity+suicurity system be built to ensure privacy safeguards without compro-

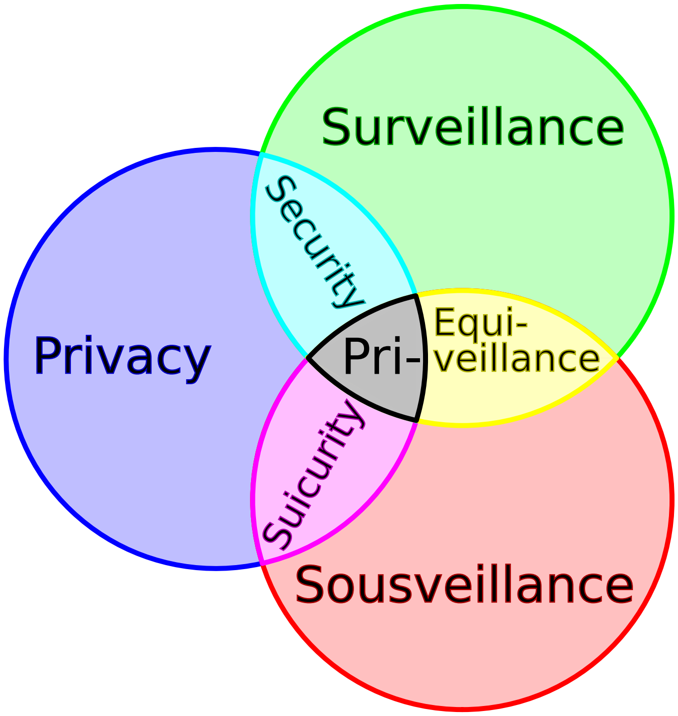


Figure 39. Privacy, surveillance, and sousveillance (e.g. wearable augmented reality, etc.). Equiveillance is the interplay or equilibrium between surveillance and sousveillance. This means that if people are under surveillance they must have a right to also capture their own version of events for their own safety and well-being as a natural extension to subject access rights. Privacy and surveillance give us security. Privacy and sousveillance give us "suicurity" (self-care, i.e. individuals looking after their own data). The grand challenge is how do we balance or manage all of this?

mising trust or requiring trust. Trust is a 2-way matter, i.e. individual bathers need to trust the establishment, and the establishment needs to trust individual bathers.

13.2. Water Justice

Water has a long history. More than 6000 years ago shepherds would camp near the water of the Gihon Spring, City of David (Jerusalem's earliest settlement), and over the years this area of land became much sought after and much fought over.

Beach access is often an issue everywhere, and beach access rights, riparian rights, etc., are a frequent source of disputes. For example, swimming is not allowed anywhere at Ontario Place which is home of downtown Toronto's only beach where at times hundreds of people swim daily, sometimes challenged by security guards. This leads us to the question of riparian rights on public lands, i.e. what does it mean to enforce a mandatory public right-of-way through *public* land?

Surveillance technology is sometimes used to keep people away from water, but also, can be used to make water accessible as for example the approach taken in Dubai to offer safe midnight swims.

Another example of water justice arises in regards to sensor-operated plumbing technology. Sensor-operated faucets and showers often use an optical sensor such as a single infrared photodiode or, more recently, infrared sensor arrays (linear one-dimensional sensor array or two-dimensional sensor array). Some of these systems are active vision systems (e.g. triangulation, depth camera, etc.).

A common problem is that persons with dark skin or dark hair get less water because their skin reflects less light and is therefore less visible to the sensor apparatus. This means that the water turns on later, and shuts off sooner as the hands or body approaches the supply of water.

In some situations, a person with extremely dark skin is unable to obtain water without placing a light colored object in front of the sensor to reflect enough light back.

Likewise showerheads with integrated sensors are sometimes less likely to turn on for someone with dark hair. These topics were explored in DECONference 2001 and have been a conference discussion topic over the past 20 years.

Recently there has been a great deal of study and research on equity, diversity, and inclusion in the context of surveillance, sousveillance, and sensing [58, 59, 59, 60].

As a thought experiment, suppose that a person could adjust their own skin color. We know that is possible on a slow time scale: John Howard Griffin, a white journalist, enlisted the help of a dermatologist to help him take large doses of methoxsalen (an anti-vitigilo drug) and spent 15 hours a day under a sun tanning (ultraviolet) lamp, so that he could pass as a black man and write about it [61]. (A similar experiment was done by Journalist Ray Sprigle of the Pittsburgh Post-Gazette, earlier [62].)

Suppose some new technology could be developed that would allow us to have a knob we could turn to lighten or darken our own skin at will? In regards to Interface Taxonomy, this would be the green circle inside the red circle (i.e. technology under our skin).

It is well known that most photographic cameras are black because they perform better in black, otherwise reflected light reduces the camera's ability to see. A similar situation holds for human eyesight. Ball players often apply black makeup underneath their eyes while playing sports. The "eye black" improves their ability to see subtle changes in light levels.

So if we had the ability to dynamically adjust our skin color, we might choose to darken it when we want to see, and lighten it when we want to be seen (e.g. by a shower or faucet).

We see therefore a richly intricate complexity between seeing (sousveillance) and being seen (surveillance), sensing and being sensed, etc., within the context of WaterHCI.

Much remains to be done to ensure that water is distributed fairly, and that "water justice" is upheld.

14. Summary and Conclusions

We have introduced and summarized the new discipline of Water-Human-Computer-Interaction/Interfaces that originated in Southern Ontario in the 1960s and 1970s, and summarized recent developments in this field, together with an overall taxonomy and ontological organization of the field in terms of borders and boundaries ("interfaces" in the wide-sense of the word).

We have also identified a number of important grand challenges.

Much remains to be done, and we are ready and eager to contribute to this work and to bring together as many others as

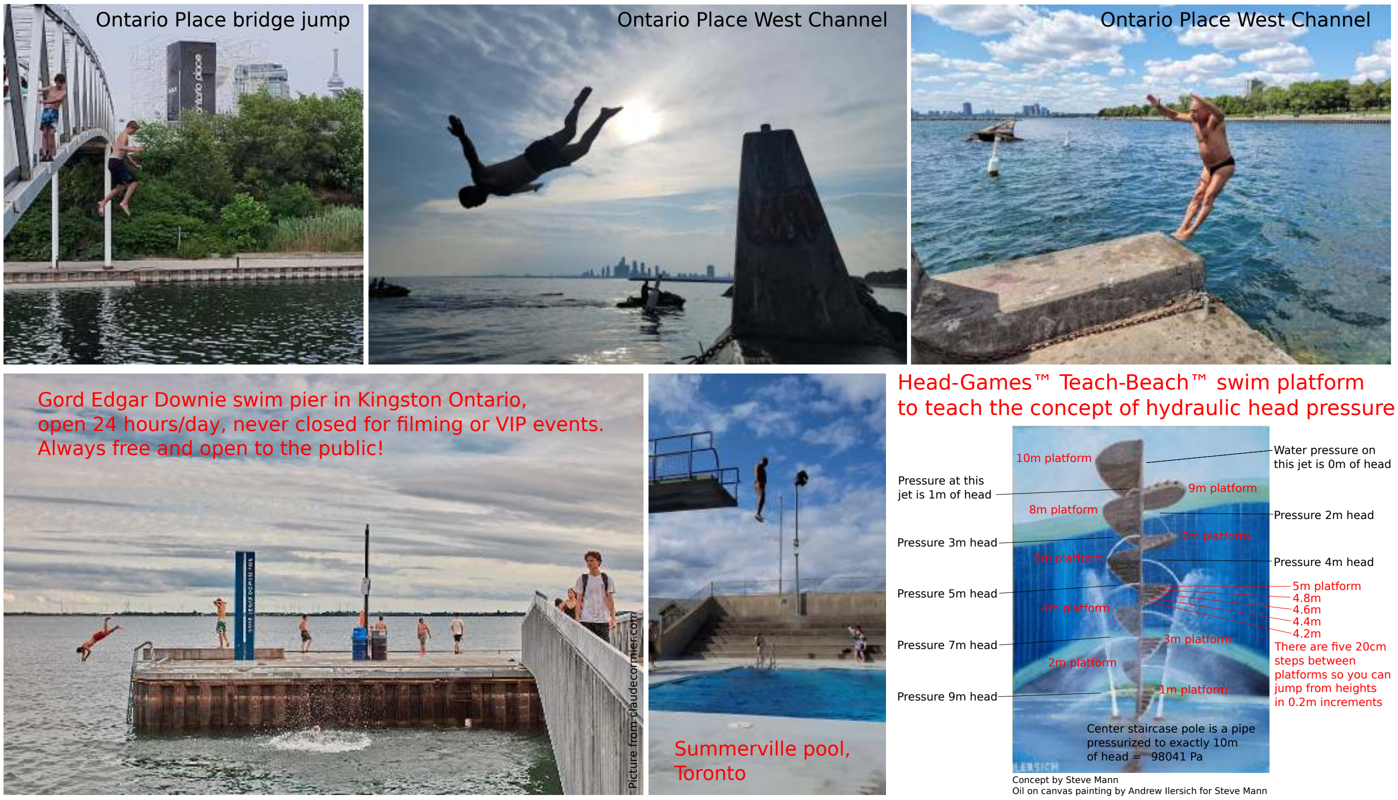


Figure 40. Understanding hydraulic head: Presently at Ontario Place children commonly jump off the bridges into the water (upper left), and people also jump off the breakwall (upper middle and upper right). A safer jumping area could be created similar to the Gord Edgar Downie swim pier in Kingston Ontario which is open 24 hours/day (lower left) or a standard pool platform could be installed (lower middle). However, we propose the Hydraulikos research platform (lower right) to facilitate an epistemology of hydrualic head. Participants can experience head in 20cm increments by way of 10 platforms at 1m increments, having stairs in which each step is exactly 0.2m. There are water jets all the way up, so participants can deadhead (fully block with fingers or hand) any jet to feel how much pressure there is. Likewise participants can feel the water as it falls from various heights. Finally participants can jump from any of a wide selection of possible heights to feel the interplay between kinetic and potential energy corresponding to that height.

wish to join us in making a good future for WaterHCI, and Fluid / Fluidic User Interaction / Interfaces.

15. Going further / Personal notes

It is our hope to create or help create an important epicenter in Toronto Ontario to celebrate the nexus of water, humans, and technology. We have named this project Hydraulikos™, and brought together major stakeholders to discuss it over the past 23 years of DECONferences. We envision Hydraulikos as a combination of a science centre, a museum + arts centre, a conference centre, a research lab, and a university for researching and teaching all elements of WaterHCI.

As a fun and playful example, we wish to see, as one element or feature of Hydraulikos, a research and teaching platform that is also fun and playful, as illustrated in Fig 40.

15.1. By any other name

It is our hope to bring together researchers, thought leaders, and the industry as a whole from all over the world. Over the past 23 years we've thought long and hard about what to call ourselves. Here are just some of the names that we came up with during our DECONferences: Water User Interface or WaterUI™, WaterHCI™, AquaHCI™, or HydorHCI™, and the like, or Wet User Interface or WetUI™, or Hydraulic HCI or Hydraulic CHI or HYDRAULIChi™, more suggestive of pressurized fluid in general, not limited to water. This led us along the lines of Fluid User-Interface™, Fluidic User-Interface™, Fluid HCI™, Fluidic HCI™, Fluid CHI™, Fluidic CHI™, FluidX™ (or replace "X" with the Greek letter Chi which looks very much like an "X"), Fluidic CHI/X™, and as more of our members evolved toward lake swims, etc., we tended toward water as a theme, while understanding that other liquids like whiskey often contain water and thus fall under the earlier terminology. More generally, we also explored other states-of-matter for dihydrogen monoxide (in addition to liquid) such as to form H2Orchestra™ which is an orchestra made of musical instruments making sound from ice (pagophone), water (hydraulophone) and steam (idratmosphone, e.g. the calliflute™). And what do we call a practitioner of this discipline, e.g. we've used the term "hydraulist", or waterborg™, steamborg™, snowborg™ (snow cyborg), and safetyborg™. Even if we never agree on what to call ourselves and our field of inquiry, we'll no doubt set forth important new directions that will make the world love and respect our waters. When one thinks of the lake as a giant musical instrument (we actually implemented this for Splash 2011!) people have tended to give it respect. We would not expect people to throw trash into a Stradivarius violin. Elevating the lake to that level helps us see water as precious and important. We hope that more of our waters become places where people swim, drink, and fish!

16. Author Biographies

Steve Mann (PhD, MIT '97, P. Eng.), is widely regarded as"The Father of the Wearable Computer"[IEEE ISSCC 2000], invented wearable computing, as well as the hydraulophone as both an acoustic instrument and as water-human-computer interaction in his childhood in the 1960s and 1970s. In the 1980s he invented HDR (high dynamic range) imaging. In the 1991 Mann and Charles Wyckoff invented, and coined the term, X-Reality (XR as eXtended Reality). Mann is a founding member of the IEEE Council on eXtended Intelligence (CXI), and a tenured full professor in the Department of Electrical and Computer Engineering at the University of Toronto.

Mark Mattson Mark Mattson is one of Canada's most seasoned environmental lawyers and the founder of several water charities, including Swim Drink Fish. He is the Waterkeeper for Lake Ontario, a water quality advisor to the International Joint Commission, a board member for the US-based Waterkeeper Alliance, and a member of Ontario's Great Lakes Guardians Council. After graduating from Windsor Law School in 1988, Mark worked at Osler, Hoskin and Harcourt, one of Canada's oldest law firms.

In 1991, Doug Chapman invited Mark to take on his first environmental case: a landfill expansion in Storrington, just outside of Kingston. Mark and Doug went into practice together, with Mark helping Doug fight some of Canada's most notorious corporate polluters. Over the years, they set a number of legal precedents, convicted polluters, put an end to projects destroying fish and fish habitat, and forced corporations to clean up contaminated sites.

Doug and Mark created the Environmental Bureau of Investigation (EBI) in 1996. This volunteer-based effort identified and prosecuted environmental offenders over five precedent-setting environmental cases. Led by Mark, the grassroots collective was comprised of community activists, scientists, and lawyers who collected evidence against water polluters in their spare time. Mark volunteered his skills as environmental investigator and prosecutor to the cause, working on cases in Kingston, Hamilton, Deloro, Moncton, and Montreal.

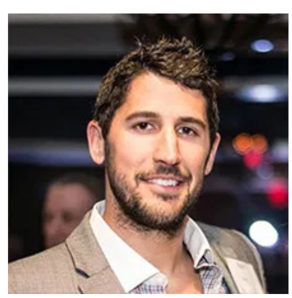
By 1997, Mark had shifted the focus of his legal work to public and nonprofit advocacy. After years in the courtroom, he began to devote more time to developing institutions and volunteer networks that could restore and protect watersheds for generations to come.

In 2001, he founded Lake Ontario Waterkeeper, an organization that gives meaning and force to environmental laws. Lake Ontario Waterkeeper grew and its work expanded beyond Lake Ontario, becoming a global movement of people working for water. In particular, Mark has championed the growth of ground-breaking programs including the Clean Water Workshop, Swim Guide, and Great Lakes Guide.

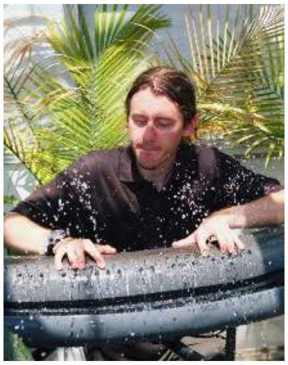
In 2010, Mark won the Toronto Community Foundation's Vital People Award, which supports leaders who are making outstanding contributions working at not-for-profit organizations.

Steve Hulford is a serial entrepreneur, currently the CEO of Underknown, the producers of the most popular Science themed video channel on the internet (Webby award winning What If). Hulford is also a member of the Friends of Cherry Beach, a group advocating for an aquatic park at Cherry Beach and Smart Buoys.

Mark Fox is Distinguished Professor of Urban Systems Engineering and Professor of Industrial Engineering and Computer Science. He is also the Director of the Centre for Social Services Engineering and the U of T Enterprise Integration Laboratory. His current research applies artificial intelligence to smart cities, and he has developed ontologies for the representation of city information and knowledge which are being adopted by cities around the world. Professor Fox has led numerous collaborations within academia and with industry and government partners, and is currently leading the Connaught-funded Urban Genome Project, a multidisciplinary initiative focused on understanding urban growth. In addition to his academic work, Professor Fox has extensive experience in the private sector. In 1984 he co-founded Carnegie Group Inc., one of the first companies to apply artificial intelligence to solving engineering, manufacturing, and telecommunications problems. He is a Fellow of the American Association for Artificial Intelligence (AAAI) and the Engineering Institute of Canada.



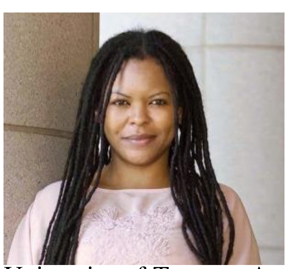
Kevin Mako Kevin is the Founder and President of the international product development firm MAKO Design. While attending one of the top business schools in North America, the Richard Ivey School of Business, Kevin incorporated the company in his third year at just 22 years old. Graduating as Class President with an additional specialization in Entrepreneurship, Kevin continued his education at the University of Hong Kong studying manufacturing and supply chain management. Using this rich wealth of experience, Kevin created the first firm in North America to offer product development services and has now transformed it into the largest consumer industrial design firm in Canada, with offices in Toronto, ON, Austin, TX, and the United Kingdom.



Ryan Janzen is a scientist, engineering researcher, and entrepreneur. Featured on the Discovery Channel, Wired magazine, and Through the Wormhole, Janzen's innovations have been featured in 110+ international lectures, media interviews, and scientific publications. Janzen's work has led to entirely new fields of research, including extramissive optics, veillance flux, swarm modulation, and the world's first aircraft PLC research. His innovations have led to advances in acoustics, aerospace electronics, mathematics, and vehicle propulsion.

Janzen is also the co-founder and CTO of TransPod, designing the next-generation of ultra-high-speed aerospace vehicles, to move passengers and cargo between cities at over 1000 km/h. Janzen is the chief architect of the multi-billion-dollar future system: transportation infrastructure, operations, aerodynamics, propulsion, and avionics. (photo: Singularity Web)

Maya Burhanpurkar graduated from Harvard with Highest Honours in Physics and was inducted into the national Phi Beta Kappa honour society. Her recent work spans biologically-inspired techniques for enhancing neural network adversarial robustness, statistical methods for detecting topological phase transitions in materials, and deep convolutional neural networks for understanding dark matter. Maya received the Queen Elizabeth II Diamond Jubilee medal, Canada's Top 20 Under 20 award, the MIT-Lemelson Prize, the Harvard i3 Innovation Challenge Gold Prize, and the John Harvard scholarship. She produced a climate change documentary with Margaret Atwood and Chris Hadfield.



Simone Browne is Associate Professor in the Department of African and African Diaspora Studies at the University of Texas at Austin. She is also Research Director of Critical Surveillance Inquiry (CSI) with Good Systems, a research collaborative at the University of Texas at Austin. CSI works with scholars, organizations and communities to curate conversations, exhibitions and research that examine the social and ethical implications of surveillance technologies, both AI-enabled and not. With a focus on algorithmic harm and tech equity, we continually question "what's good?" in order to better understand the development and impact of artificial intelligence.

Craig Travers is a Senior Engineer at Vuzix, the leading augmented reality technology innovator. Growing up in upstate New York instilled in him a sense of curiosity and adventure. Travers has worked for the most prestigious tech companies such as General Electric and Xerox until he decided to provide his expertise to Vuzix with the company's CEO and brother, Paul, from their family basement. It sparked a revolution in augmented reality and athletics that is bound to change the name of the game.

Robert Thurmond has more than 20 years of experience managing the successful execution of strategic communications and marketing projects within a wide array of industries and project types, including: healthcare, publishing, financial management, energy efficiency, education, and localization/multi-lingual language services.

Seung-min Park
Dr. Seung-min Park is an Instructor in the Department of Urology at Stanford University School of Medicine. He received his Ph.D. in Applied Physics from Cornell University in 2008. During his postdoctoral training (Bioengineering) at the University of California, Berkeley, he was also a visiting scholar at the Universidade Federal do Rio de Janeiro in Brazil as part of his devotion to Global Health. Afterwards, he joined Stanford University as an Instructor and focused on developing cancer diagnostics based on nanotechnologies. His research interests lie at the convergence of nanobio-engineering, disease diagnostics, and their applications to those who suffer from healthcare disparities.
Website: https://profiles.stanford.edu/seung-min-park

Atlas Roufas is an entrepreneur, inventor, and artist who specializes in the intersection of technology and art. In his early 20s he founded Spiral Graphics Inc, a company that focused on the creation of software tools for 3D artists building digital worlds for games and movies. The startups he has been involved in since then have specialized in a variety of creative areas, including designing mobile games and

spearheading the development of voice-powered interactive fiction for the Amazon Alexa digital voice assistant. In 2017, he co-founded Ballast Technologies, Inc, a company dedicated to the development of aquatic virtual reality, where he played a role in building the company into the recognized leader of virtual reality solutions for water parks. He continues at that company as Chief Content Officer, where he leads the design and development of their virtual reality experiences.
Website: www.ballastvr.com

Cayden Pierce is a researcher, engineer, and designer focused on expanding human experience and intelligence. Cayden has researched novel wearable computing use cases, brain sensing techniques, meta-sensing technologies, fitness tools, and other inventions at the center of cyborg intelligence augmentation. As *BCI Research Lead* at *Blueberry*, he helped develop the world's smallest and cheapest brain-computer interface (BCI). As *Wearable Computing Advisor* at the University of Toronto, Cayden helped launch the wearables stream at the Creative Destruction Lab (CDL). Cayden is currently leading the development of the open source "Wearable Intelligence System" at Emex Labs.
Website: caydenpierce.com

Samir Khaki is an engineering student at the University of Toronto specializing in machine learning, signal processing, and mechatronics. With a background in software development, Samir has made several research contributions to fields including artificial intelligence and robotic sensing.

Derek Lam is an engineer of all things with a current flowing through them. He has a varied and eclectic background working with epidemiologists, environmental engineers, neuroscientists and usability engineers to shape the way that electronics affect the lives of those that they serve. Derek is deeply invested in the intersection of engineering and usability, creating the interactive "Hello Neighbour" exhibit at the EDIT Design Festival for disease analytics with BlueDot Inc., developing sensory augmentation technologies at MannLab, and researching static analysis tools for open-source reactive user interfaces. As a senior device engineer at Microchip, Derek currently investigates the physics and feasibility of some of the smallest transistors on earth.

Faraz Sadrzadeh-Afsharazar is a researcher, hardware designer, and electrical engineer specializing in electrical stimulation, human-computer interfaces (HCI), visual prostheses, and analog electronics. Faraz is the co-inventor of the world's first fully wearable Phosphotron, a visual prosthesis that electrically stimulates the facial skin, allowing a visually impaired individual to see flashes of light that entail spatial information of the wearer's surroundings. Faraz is currently developing open wound imaging technologies at Swift Medical.

Kyle Simmons was Electromechanical Wizard at Active Surplus, Canada's legendary hub for makers and the birthplace of the world's first wearable computer made by Steve Mann. Before that, he led R&D at an educational robotics company delivering custom solutions to a wide range of clients. His experience with physical neural networks, air-engines, and human-machine interfaces earned him a reputation as an in-demand project freelancer for clients ranging from major corporations to renowned film directors.

Tomoko Yonezawa is a Researcher of Human Communication Design with using robotics, virtual agents, overlapping virtual reality as environmental intelligence, and so on.

Her main field is based on virtual communications including human-agent/human-robot multimodal interaction including gaze, voice and touch, virtual reality, digital music, etc.

She was intrinsically interested in musical expressions especially about the primitives of the music such as code and melody generation since she was a pops composer for not only personal but also commercial purposes. Accordingly, her past original field was related to music and expressiveness.

Ateeya Manzoor, I've spearheaded corporations for over two decades. A solution seeker at the core, my interest in the decision making of visionaries and organizations sparked in 2000, where I was asked to study hundreds of management information circulars for Merrill Lynch clients. My role was to comprehensively understand the reasoning behind each board decision and advocate to attain shareholder quorum.

This launched a career working for multinational risk management firms and financial institutions, in Toronto, London, Los Angeles and Silicon Valley, assessing business risk vs. opportunities and working to help EAT (eliminate, transfer and/or assume) it.

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