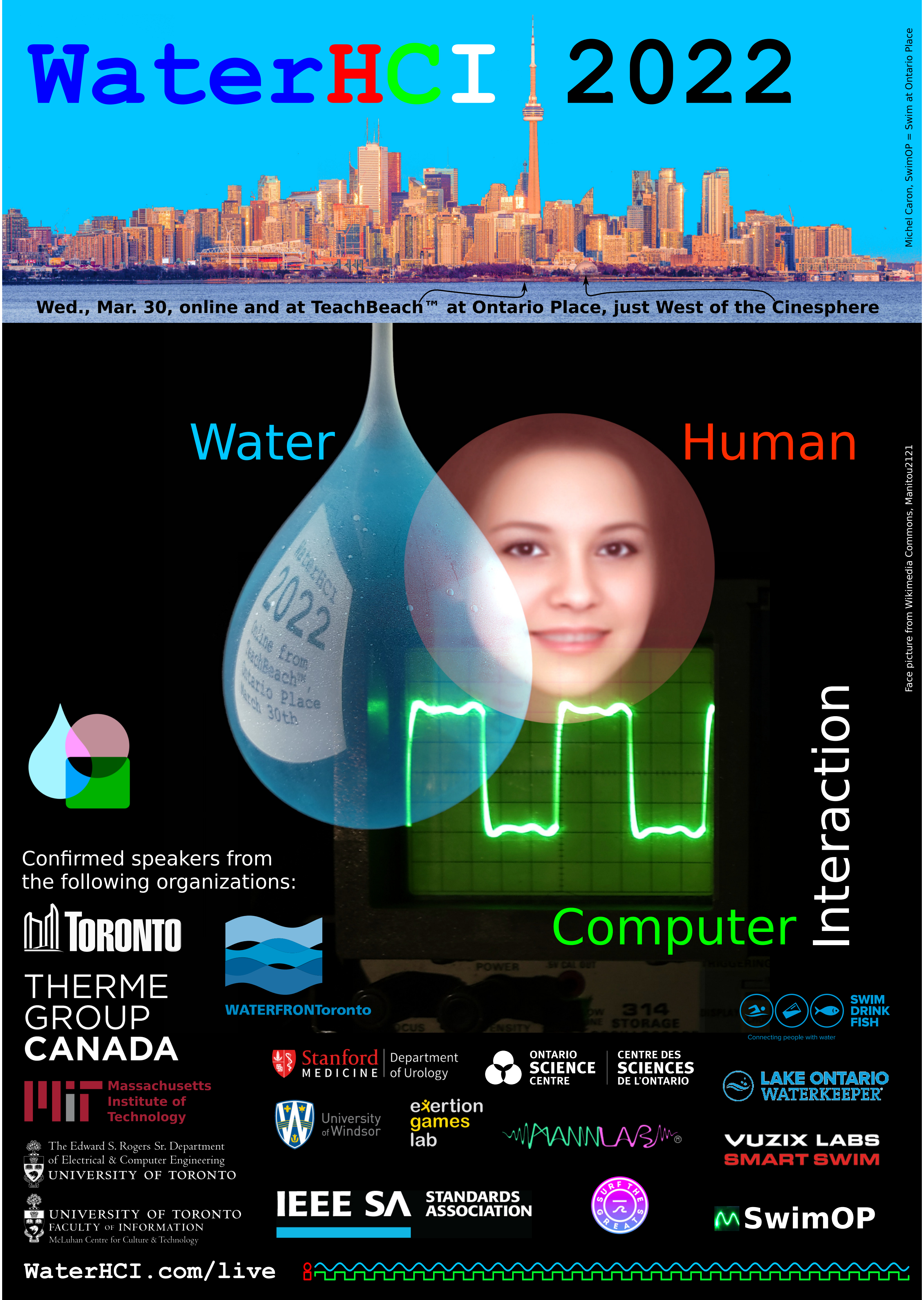
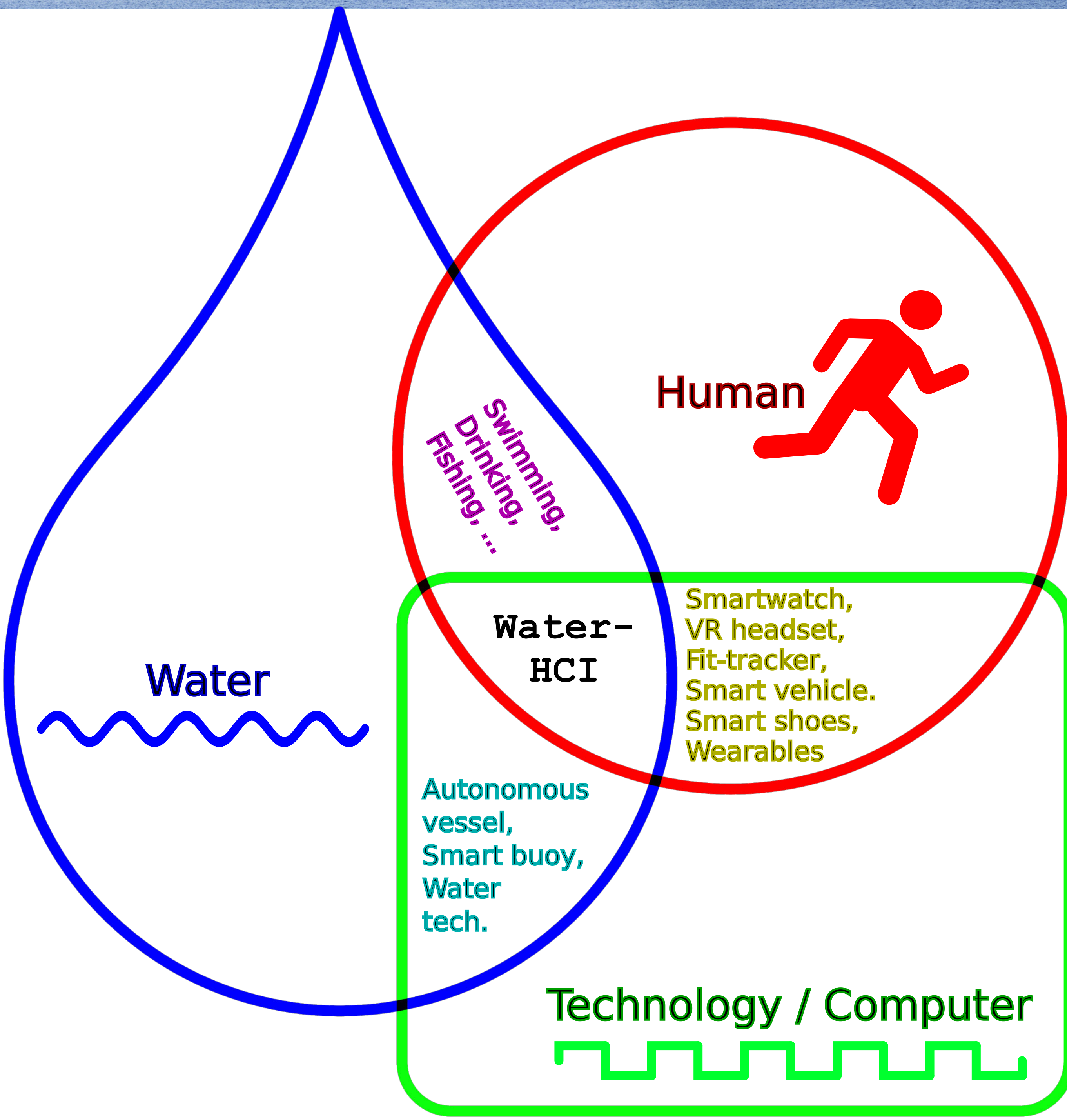

WaterHCI 2022
Michel Caron, SwimOP = Swim at Ontario Place
Wed., Mar. 30, online and at TeachBeach™ at Ontario Place, just West of the Cinesphere
Water
Human
WaterHCI 2022 Online from TeachBeach™, Ontario Place March 30th
Face picture from Wikimedia Commons, Manitou2121
Interaction
Computer
Confirmed speakers from the following organizations:
TORONTO
THERME GROUP CANADA
WATERFRONToronto
SWIM DRINK FISH
Connecting people with water
Stanford MEDICINE Department of Urology
ONTARIO SCIENCE CENTRE
CENTRE DES SCIENCES DE L'ONTARIO
LAKE ONTARIO WATERKEEPER
Massachusetts Institute of Technology
University of Windsor
exertion games lab
VUZIX LABS SMART SWIM
The Edward S. Rogers Sr. Department of Electrical & Computer Engineering UNIVERSITY OF TORONTO
IEEE SA STANDARDS ASSOCIATION
SURF THE GREATS
SwimOP
UNIVERSITY OF TORONTO FACULTY OF INFORMATION McLuhan Centre for Culture & Technology
WaterHCI.com/live

WaterHCI 2022

Michel Caron, SwimOP = Swim at Ontario Place



Proceedings of the 24th annual WaterHCI DECONference

WaterHCI 2022

The TeachBeach concept at the intersection of water, humans, and technology

Wednesday, March 30, 2022

Online (www.waterhci.com) and at the TeachBeach™ at Ontario Place, Toronto, Ontario, Canada

Overview of Annual WaterHCI DECONference

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 and the importance of clean water, noting that Toronto is regarded by many as the world's epicenter of freshwater.

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 WaterHCI DECONference series were presented on Capitol Hill in Washington DC and informed the design of hospitals across the United States and around the world for pandemic preparedness.

WaterHCI DECONference 2011 (November 22nd, 2011) brought together stakeholders from University of Toronto, City of Toronto, Waterfront Toronto, Ladies of the Lake, and other organizations regarding the construction of a more permanent version of the TeachBeach in downtown Toronto.

Last year at WaterHCI-2021 we identified grand challenges in the new field of WaterHCI, and proposed a new taxonomy/ontology/classification system for research and practice at the intersection of water, humans, and technology.

Since 1998 the annual WaterHCI DECONference has been a collaboration between the Department of Electrical and Computer Engineering and the McLuhan Program.

This year the 24th 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)

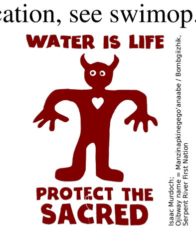
Inclusivity: Our school (academic) year runs from September to April. April is exam month, marking the end of the academic year. This year we decided to have the DECONference at the end of the school year, i.e. just before April exam month, so that students could participate more easily in the context of their final projects, etc.. See for example, www.wearcam.org/ece516/lab5.htm

This year we are also focusing more locally, e.g. with our local Indigenous communities, civic communities, and local (municipal and provincial) stakeholders at downtown Toronto's only beach, at Ontario Place, with an emphasis on what we call Ontario Placemaking™ .

DECONference is an inverse conference, and includes an element of spiritual cleansing, taking to the waters, washing away (DECONtaminating) our preconceived notions of what conferences are normally like. We come together with a single paper publication, rather than multiple disparate papers.

Schedule: 2022 Mar. 30, Eastern Daylight Time

- 9:30am Elemental/Matter Acknowledgement: We respectfully acknowledge the Land, and more generally, **all** states-of-matter ("Elements"), e.g. Land/Earth (solid), Water (liquid), Air (gas), and Fire (plasma), at Ontario Place, irrespective of when the Land/Earth/property was "built". This space is traditional space of many, including the Mississaugas of the Credit, Anishnabeg, Chippewa, Haudenosaunee and Wendat peoples and is home to many First Nations, Inuit and Métis. We pay respect to their elders, past, present, and future, who have been and will continue to be stewards of matter here.
- 9:45am Premiere release of Time (music video shot at the TeachBeach at Ontario Place), song by Monique Barry, video by Dan Bowman.
- 10:00am Stephen Diamond, Waterfront Toronto
- 10:30am Pierre Lafontaine, National Swimming Coach & CEO, 2012 Canadian Olympic and Para-Olympic Team, Director, Therme Group Canada, Inc.
- 11:00am Mike Layton, City of Toronto stormwater plans
- 11:30am Mark Mattson, Swim Drink Fish, Making world-class swim piers, free and always open 24 hours/day
- 12noon - 2:00pm: Break for Spirtual Healing with water, led (remotely) by Youngblood (Mohawk) and Candyce (Missisaugas of the Credit): travel to TeachBeach™ at Ontario Place. For location, see swimop.com/where



- 1pm: Ancestral spiritual warrior cleansing ritual and ice-water swim: Icewater immersion begins.
- 1:30pm Return from Ontario Place
- 2:00pm Steve Hulford, swam over 200km in Lake Ontario, Smart Buoy Project
- 2:30pm: Prof. Chris Houser, University of Windsor, Smart Beach Project
- 3:00pm: Dr. Newell, Ellis Aquatic Vigilance System (EAVS)
- 3:30pm: Chi Nguyen
- 4:00pm (1pm California time) Dr. Seung-min Park, Stanford University: World's most advanced water-saving and covid-preventing toilet
- 4:30pm Jason Baerg and Ana Klasnja, Water in the New World
- 5:00pm Fadel Adib, Massachusetts Institute of Technology, Bringing the Internet of Things to the Underwater World
- 5:30pm Break / Discussion / Student presentations
- 6:00pm (9am Thu. Mar. 31 in Monash) Florian 'Floyd' Mueller and Christal Clashing, Designing for Interactive Aquatic Recreation
- 6:30pm Madeline Leblanc, Surf the Greats, SUP surfing on the Great Lakes
- 7:00pm (7am Thu. Mar. 31 in China) Yu Yuan, IEEE Standards Association President-Elect, Standards for WaterHCI

WaterHCI: Exploring the intersection between water, humans, and technology.

Steve Mann, Mark Mattson, Steve Hulford, Seung-min Park, Fadel Adib, Chris Houser, Stephen Diamond, Pierre Lafontaine, Florian Mueller, Christal Clashing, Jason Baerg, Ana Klasnja, Zhao Lu, Samir Khaki, Puneet Bagga, Chufan Luo, Kyle Simmons, Jaden Bhimani, Calum Leaver-Preyra, Santiago Arciniegas, Yuxuan Liu, Leon Lei, Tony Tao, Candyce Marcotte, Youngblood*

WaterHCI-2022, March 30th, Toronto, Ontario, Canada

Abstract

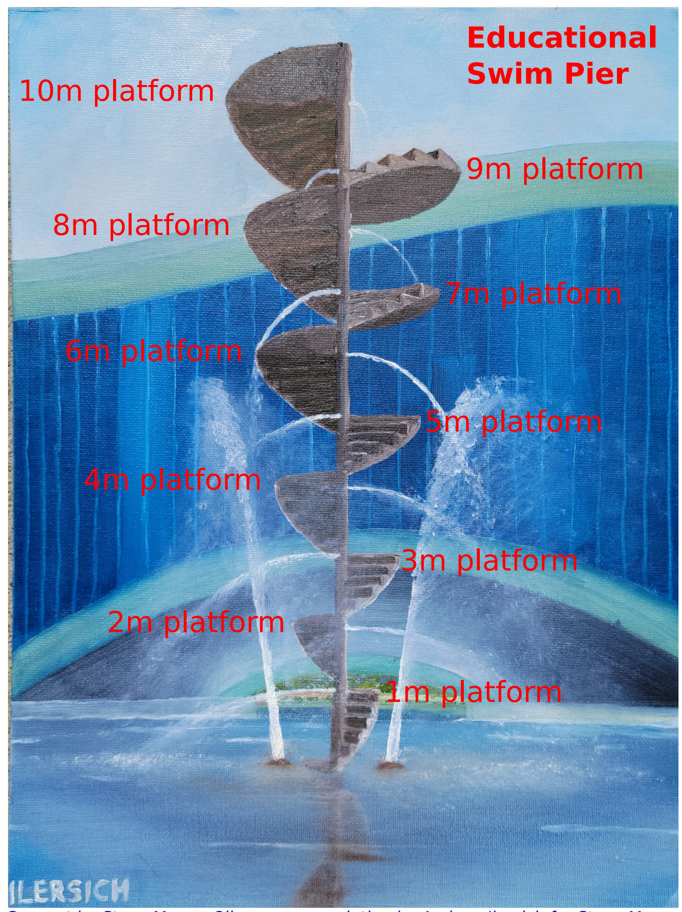
WaterHCI (Water-Human-Computer Interaction) is a field of study and practice focusing on the design and creation of interactive devices, systems, and experiences at the intersection of water, humans, and technology. It is a relatively new field that originated in Ontario, Canada, in the 1960s, and was further developed at University of Toronto through a series of annual (de)conferences from 1998 to present.

This year, at our 24th annual WaterHCI (de)conference, we focus our attention on ideas for creating spaces and places (e.g. Ontario-Placemaking™) that combine fun and frolic with health and wellbeing, nature and spirituality, research and teaching, and innovation, where we can touch and be touched by water.

1. Educational Swim Pier: example at the intersection of water, humans, and computation

Water is universal and inclusive at the intersection of health and wellbeing, fun and frolic, the sacred and the sublime. We envision the creation of inclusive space that simultaneously celebrates and facilitates fun, frolic, exercise, health, wellbeing, sustainability, art, culture, science, mathematics, innovation, research, education/teaching, spirituality, arts, and culture for people of all ages, backgrounds, and experience levels from early childhood to post-doctoral/professorial/professional. We name such space Hydraulikos [1], as a "placeholder" until we find a better name. Hydraulikos might take the form of a beach, waterpark, wellbeing resort, thermal spa, or combination of these, combined with an onsite scientific research lab, university, science centre, art gallery/arts centre, etc..

As an example of something you might find at Hydraulikos, consider the art/sculpture/science/teaching creation depicted in Fig 1. This is a swim pier with ten platforms at 1 metre high increments from 1m above the water all the way up to 10m (same as a standard Olympic pool platform). This allows swimmers to experience the water from ten different elevations and understand exactly what it feels like to drop from each of these heights. Each platform is labeled with its height, the speed at which one hits the water jumping from that height, and the time in seconds that one spends in the air while dropping from that



Concept by Steve Mann. Oil on canvas painting by Andrew Ilersich for Steve Mann.

Figure 1. Educational Swim Pier with ten platforms that swimmers can jump from, spaced at 1m intervals. Each platform is labeled with its height, as well as the speed at which one enters the water when jumping from that height, and the time-in-the-air when jumping from that height. This art/science/educational installation turns math and physics into fun and frolic.

*We wish to thank the Marshall McLuhan Program in Culture and Technology, AMD, Vuzix, and the 897 members of SwimOP = Swim at Ontario Place (swimop.com and facebook.com/groups/swimop) where much of this research took place. See also our Land and other Matter Acknowledgement

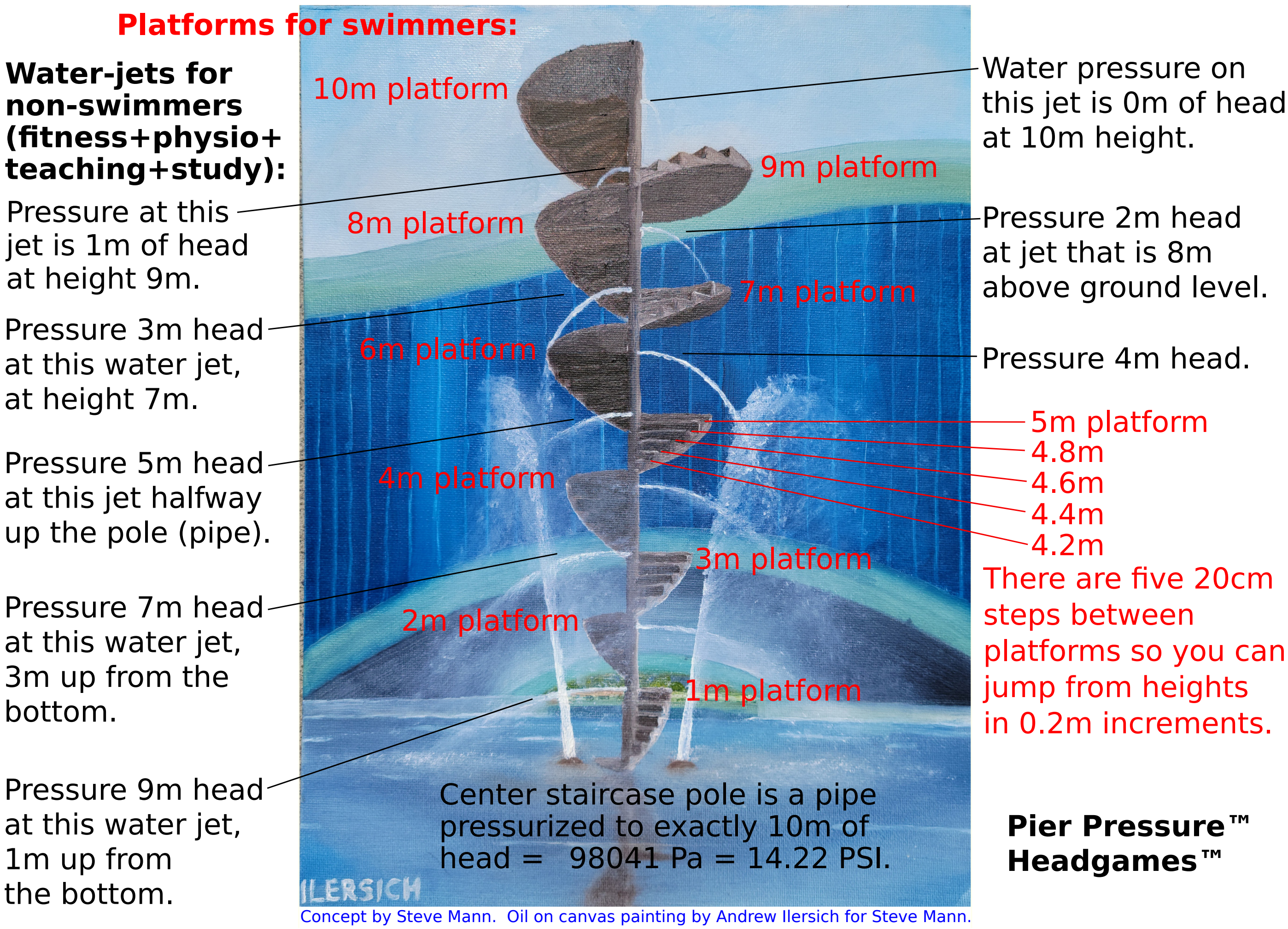


Figure 2. Each platform of the swim pier has a water jet that participants can block with their fingers to feel the reduction in head pressure as they climb up each level. We can start to understand why water pressure is less in the upper floors of a building than it is at the ground floor.

height (which is approximately the square root of one fifth the height).

Moreover, there are exactly five steps (stairs) from each platform to the next one, such that each step is exactly 0.2m (20 centimeters), thus making it easy for a swimmer to jump from heights in-between the 1m increments, and still know the exact height, e.g. 1m, 1.2m, 1.4m, 1.6m, and so on, and thus be able to easily calculate velocity of entry and time-in-the-air when jumping from that step.

The steps and platforms form a circular staircase around a central pole which is itself a hollow pole, i.e. a pipe, into which water is pumped, as shown in Fig 2. At each platform there is a small hole in the pipe, with water coming out. The pipe is pressurized to exactly 10m of head (approx. 393.7 inches of water column). A pressure of 10m of head is the amount of pressure required to raise water up 10m $\approx$ 393.7 inches $\approx$ 32.8 feet. In this way the top hole at the 10m platform will have exactly zero head pressure, and the water will be at the exact pressure at which the rate of flow is exactly zero.

At the 9m platform, there will be a pressure of ten minus nine metres of head which equals 1m of head. At the 8m platform there will be 2m of head, and so on. Thus swimmers can understand the exchange between potential energy (from being way up in the air) and kinetic energy (moving through the air), flow, and head. These concepts are understood in a fundamentally new way, through "being" the falling object rather than merely watching an object fall. We call this "learn by being" (existential education) [2]. Learn-by-being (LBB) results in a fundamentally deep understanding of the simple laws of math and physics while engaged in fun and frolic.

Additionally the piece is accessible to all persons of all abilities in the sense that non-swimmers can still experience the head pressure, e.g. by blocking each hole with their fingers so that they can learn what 1m of head feels like, 2m of head, 3m, 4m, and so on. Additionally the water jets and their respective heads (pressures) are replicated on another piece of pipe at ground level so that the elderly or infirm (e.g. those unable to climb the steps) can touch each water jet in a row of water jets labeled 1m, 2m, 3m, ... 10m of head, each bearing the corresponding head pressure. In this way participants can let their fingers do the swimming, and still benefit from the educational aspects of the piece, even if they can't swim or climb stairs.

Inside each of the water jets is an underwater whistle so that when deadheading (totally blocking) a jet, a corresponding mu-

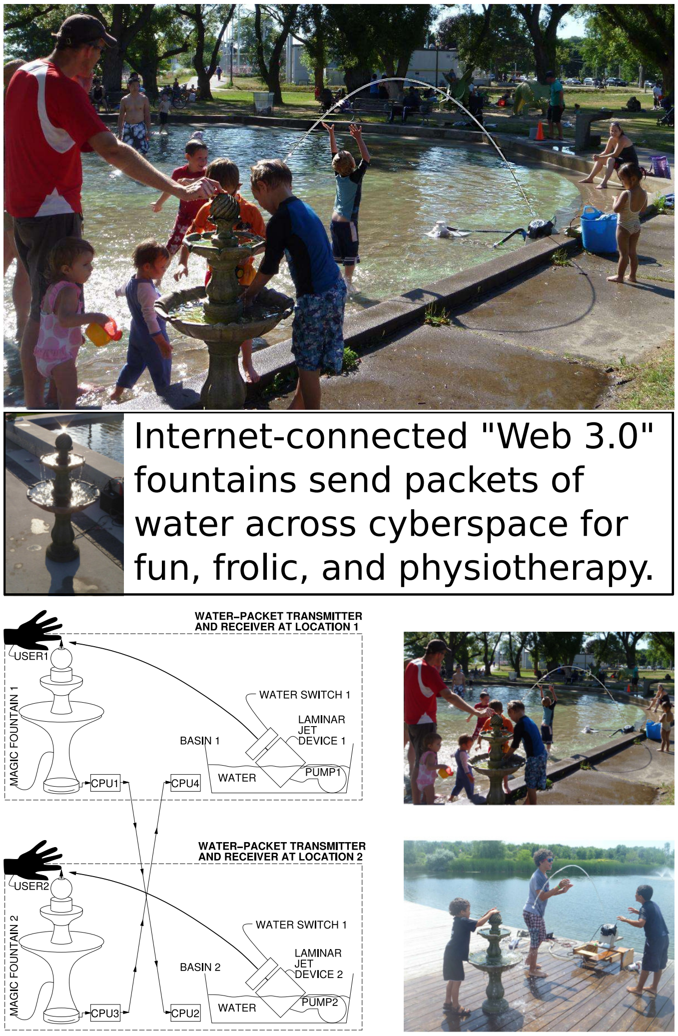


Figure 3. Architouch™ is an Internet-of-Things-That-Think (IoTTT) installation using Internet-connected fountains to allow participants to send water-packets across cyberspace and play video games in which the pixels are packets of water [1].

sical note is sounded. Thus there are notes on a musical scale that teach the relationship between pressure and Karman vortex shedding phenomena.

In this way the swim pier is a math + physics + research + teaching lab, upon which ongoing research may be conducted in such a way as to attract amateur scientists and hobbyists to envision their own experiments at the nexus of fun and frolic.

Other features of Hydraulikos include interactive water jets using WaterTouch™ technology in which water jets are Internet-connected control/touch surfaces (Fig 3), or like "keys" on a musical instrument, each jet playing a different musical note (Fig 4). Such forms of water-human-machine interface have been useful as a form of tactile user-interface that appeals to the blind and deaf-blind [3].

2. Water is life

Water is an unquestionably essential resource for life as we know it. It makes up most of our bodies, covers the majority of our planet, and plays a key role in defining global climate patterns. Water sustains us. As animals, we need drinking water just to be alive. As modern humans, we need water to cook, to generate energy, and even to build skyscrapers. Water moves us. The sound of light rainfall can calm our overstimulated minds. The shimmering stillness of Lake Ontario at Ontario Place can enthrall an agitated soul. The range from calm to powerful forces of the waves, or perhaps an icewater swim, can invigorate a weakened spirit. Water (and ice!) is therapy. For many of us at SwimOP, who swim year-round at downtown Toronto's only beach, water and beach access are essential medical or spiritual necessities. Water is physiotherapy and may form a medically necessary icewater immersion intervention for a shoulder injury, or for mental health. In this way free unrestricted beach access, i.e. a right-of-way that leads to the beach, is essential.

Figure 4. The hydraulophone is a machine that uses mechanical/hydraulic computation to generate vibrations ("sound") in water as a form of musical performance/instrument, as well as physiotherapy. Live performance as the headline act for Winterlude, North America's largest winter festival.

Water also inspires us. Ancestral wisdom has intertwined water with our spirituality. Multiple cultures and religions have grown to revere it as a divine substance, celebrating it in the shape of holy water, fountains of youth, purifying rituals, such as the Indigenous warrior cleansing rituals, and more. Water is us, so it is evident that disconnecting from it, polluting its sources, and neglecting its connection to research and technology will bring harm to humankind.

Nobody has a right to own our lakes and rivers, or to exclude anyone from entering them at any time they wish. To say that a beach or park is "closed" at a certain hour, such as 11pm, or time or day, for any reason, should be called into question. For example, Ontario Place is "closed" at 11pm, but many baptisms or Indigenous cleansing rituals take place at exactly midnight, under the light of a full moon. We see no reason to prohibit safe practice of spiritual healing at any time that is desired among the peoples of many diverse beliefs and cultures, and thus we see it is essential to provide a 24 hour/day right-of-way access to the water that cannot be closed for any reason regardless of what commercial interests or private rentals of the space might occur. It has been said that "beaches by tradition and in concert with British common law are properly the preserve of the public and the public's right to access these beaches needs to be reaffirmed" and a bill is being proposed that "provides a fine of up to $2000 if the public is improperly blocked from enjoying access to Ontario's beaches along the Great Lakes".[shorewalk.ca] Maybe we need a new field of study like liquid sur/sous/méta/veillance – "Eauveillance™" or "Justeau™".

In addition to ShoreWalk.ca there are the Indigenous water walkers who draw on tradition to raise environmental awareness.

WaterHCI-2022 takes place in the ancestral Anishinaabe and Haudenosaunee Confederacy land as determined by the Dish with One Spoon Treaty. The intent of this agreement is for all nations sharing this territory to do so responsibly, respectfully and sustainably in perpetuity. We respect the longstanding relationships with the local Indigenous communities, the Mississaugas of the Credit First Nation and the Six Nations of the Grand River, and must honour our lands and water which we all share with one another. It is for this reason that we begin our DECONference with not just a Land Acknowledgement but also an Elemental Acknowledgement (Matter Acknowledgement), followed later by an Indigenous warrior cleansing ritual informed by Youngblood (Mohawk) and his wife Candyce (Missisaugas of the Credit), with input also from Indigenous artist Jason Baerg (Métis Nations of Ontario), also informed by Cree and Ojibway tradition where the Water section of the Medicine Wheel is represented by the color blue. We acknowledge not just the Land (i.e. the Element, Earth, i.e. matter in its solid state), but also all the Elements (Earth, Water, Air, Fire), i.e. matter in all states-of-matter (solid, liquid, gas, plasma), as suggested in Fig 5.

Water is a force that unites us in a common purpose, and to develop a technological and computational world separate from it, is a disservice to humanity.

McLuhan wrote that the computer is humankind's most extraordinary technological clothing; it's an extension of our central nervous system [4]. Whereas the computer is perhaps our greatest achievement, it is wrong that the field of HCI (Human-Computer Interaction) has for the most part been separated from water.

Indeed, humans and technology have merged to form the cyborg entity. Manfred Clynes who coined the term "cyborg" cites a human riding a bicycle as his favorite example [5]. But we proffer that a human on a vessel (boat) is just as much cyborg as when riding a bicycle, and thus cyborgs have been in existence for more than a million years — long before the invention of the wheel, the invention of clothing, and even the existence of homo sapiens. Therefore we find it surprising that water is not more central to human-technology discourse and practice.

Accordingly we created the WaterHCI initiative in Ontario, Canada, to address this deficiency.

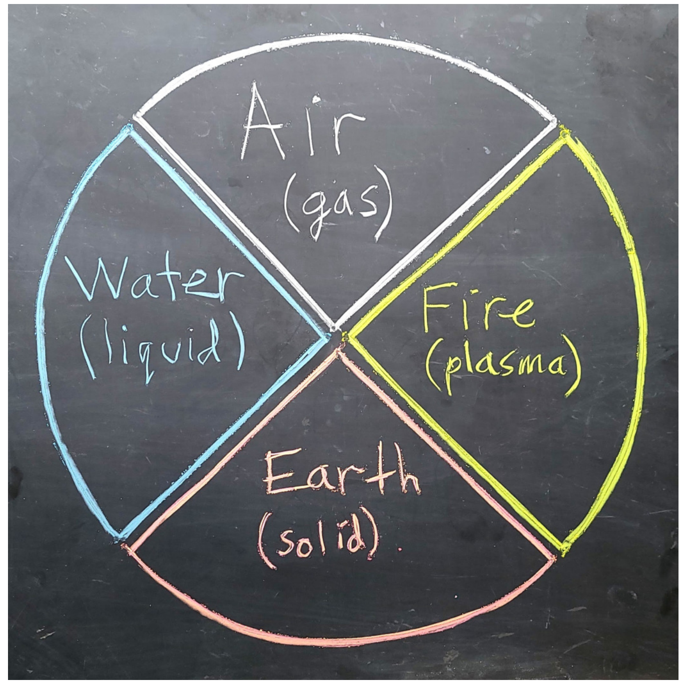


Figure 5. We acknowledge all matter, not just Land = Earth = solid matter, thus the Elemental Acknowledgement (Matter Acknowledgement) and the Indigenous warrior cleansing ritual of Youngblood (Mohawk) and his wife Candyce (Missisaugas of the Credit), following also the Métis tradition of artist Jason Baerg, and his understandings of the Cree and Ojibway traditions. In this way Ontario Place is still sacred land, because it was made from and in sacred Elements (e.g. in the lake), even though the "Land" there was "built" or appeared relatively recently in human history.

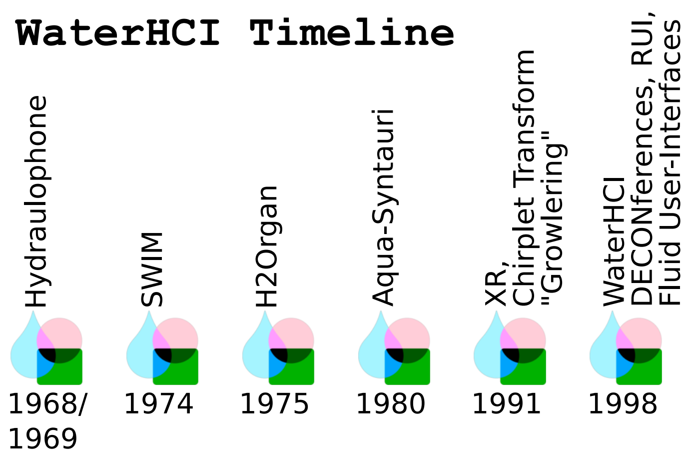


Figure 6. WaterHCI Timeline

3. Some highlights from past WaterHCI DECONferences

The WaterHCI DECONferences began in 1998 after about 30 years already of development (see Timeline in Fig 6). An important element of WaterHCI was the SWIM (Sequential Wave Imprinting Machine) [6, 7] that turns marine radar, sonar, and

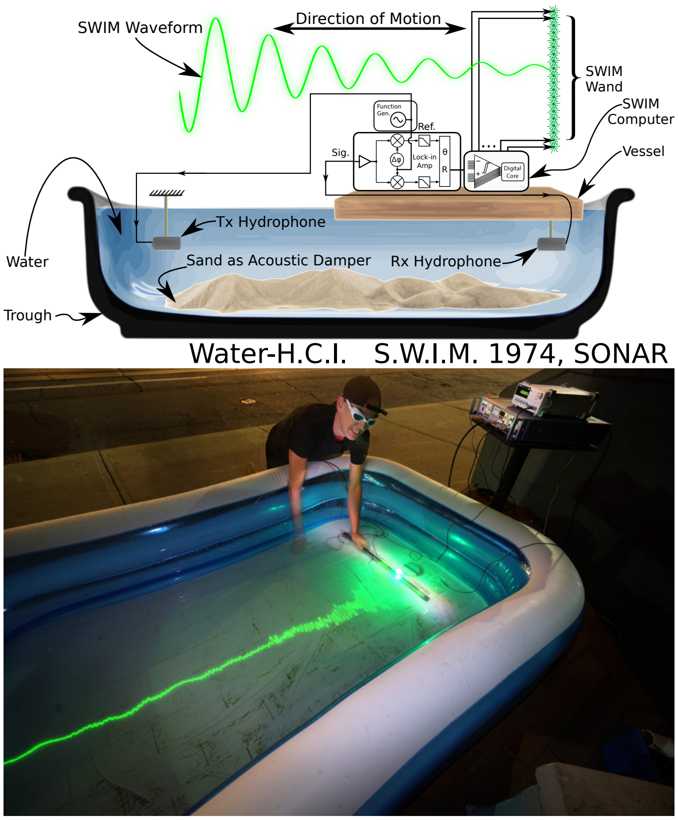


Figure 7. Early WaterHCI based on the SWIM (Sequential Wave Imprinting Machine), invented in 1974, turned marine radar, sonar, etc., into interactive eXtended Reality (XR) spaces to explore waves in air, water, and solid matter. In the original embodiment, a small trough was used with a small toy boat or other small vessel for interactive realtime exploration. Top figure from [9]. This work led to the invention of the Chirplet Transform [10] for detection of growlers (small ice fragments) in marine radar. Presently SWIM is still regularly used in teaching and research (e.g. using a small wading pool, which nicely absorbs spurious sonar reflections).

other sensing technologies into fully interactive closed-loop educational spaces using XR (eXtended Reality) [8]. See Fig 7.

WaterHCI DECONference 2007 took place in Copenhagen where we temporarily turned Vandkulturhuset DGI-byen Aquatic Centre (a massive wellness resort complete with a banquet hall on an island in the middle of a giant pool) into a research lab + underwater concert space (Fig 8).

For WaterHCI DECONference 2011 (November 22nd, 2011), we brought together First Nations, such as First Nations musicians David and Kimberly Maracle, from the Tyendinaga Mohawk Territory, along with Waterfront Toronto, University of Toronto, and Ladies of the Lake, to envision Hydraulikos in the context of ancestral teachings within Toronto's waterfront community (Fig 9), regarding the construction of a more permanent version of the TeachBeach in downtown Toronto.

At WaterHCI DECONference 2021 we summarized grand challenges in the new field of WaterHCI, and proposed a simple taxonomy for understanding how humans interact with water and technology. The resulting Mattson-Mann taxonomy is illustrated in Fig 10. We invited a number of the world's top researchers to present their work, including Stanford University's smart toilet, and a variety of underwater VR technologies such as Vuzix SmartSwim, Ballast VR, and AREEF [11].

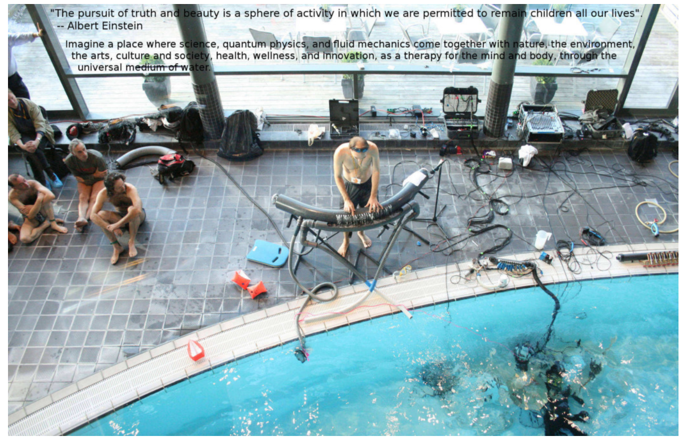


Figure 8. WaterHCI-2007: Celebrating Albert Einstein's belief we should remain children all our lives... "Imagine a place where science, quantum physics, and fluid mechanics come together with nature, the environment, the arts, culture and society, health, ... through the universal medium of water."

Figure 9. WaterHCI DECONference 2011 brought together First Nations, Waterfront Toronto, University of Toronto, and Ladies of the Lake, to envision a waterfront research + fun + frolic + teaching space that includes ancestral teachings.

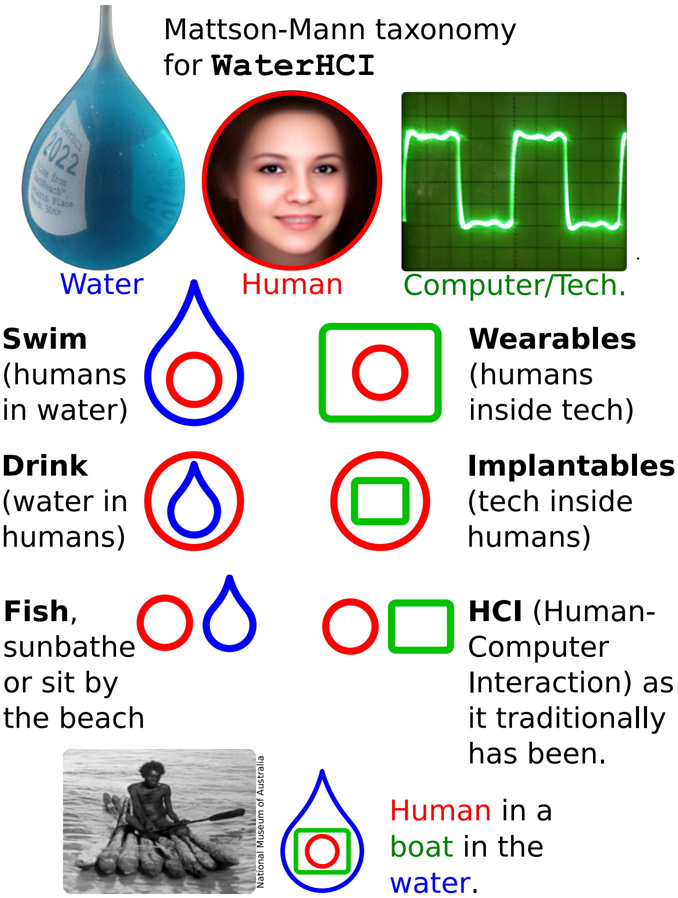


Figure 10. **The Mattson-Mann taxonomy:** There are three ways humans can interact with water: (1) we can put ourselves into the water (e.g. swim); (2) we can put the water into ourselves (e.g. drink), or we can engage with the water as a separate entity, e.g. we can fish, or sunbathe or sit by the lake and mediate to the sounds of the waves. There are also three ways humans can interact with technology: (1) we can put ourselves inside the technology by entering a vessel such as a boat or car or clothes (e.g. we regard boats and cars and clothes as “wearables”); (2) we can put the technology inside us (e.g. “implantables”), or (3) we can engage with technology as a separate entity, e.g. traditional HCI (Human-Computer Interaction) and desktop computing. As an example of applying the taxonomy more generally, consider a human in a vessel in the water, as indicated along the bottom row.

Another highlight of WaterHCI-2021 was Florian “Floyd” Mueller’s presentation, “Towards beginning to understand WaterHCI”. Consider the taxonomy proposed by Raffe *et al.* from Mueller’s research group (Fig 11) [12]. This taxonomy considers the degree of water contact, e.g. that being in the rain involves less water contact than being on a boat. Whereas a boat does contact a large quantity of water, we proffered that being in the rain is not really less water contact to the human body than being on a dry deck of a boat on a sunny day. So what we really need is a 2nd dimension, giving rise to the headflow

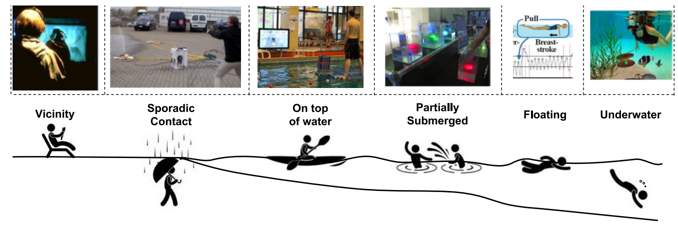


Figure 11. Six degrees of water contact.

Figure 12. Headflow Taxonomy as presented at the TeachBeach outdoor classroom at Ontario Place as part of WaterHCI DECONference 2021. The outdoor classroom was constructed from debris recovered during beach cleanup (removal of sharp and dangerous metal objects on the lake bottom near the shore where many people swim), and formed the venue for WaterHCI-2021.

taxonomy in which we have the quantity of water going from left to right, and the pressure (head) going from bottom to top, arranging these and other situations along a two-dimensional rather than one-dimensional axis, as presented in our outdoor classroom at one of our icewater swims. See Fig 12. Another possible space to consider is pairwise permutations of Water, Human, and Computer/Tech, as shown in Fig 13.

Additionally we created an Android app that simulates the 1974 SWIM, i.e. that turns nearly any waterproof Android smartphone into an interactive SONAR. The sonar can work in air, water, or even in sending sound waves through solid matter.

The first screen of the app provides an introduction to SWIM and visualizations of the three options of SWIM. By selecting one of the three options, the app goes to the second screen, where users can freely select transmit wave types (square, triangle, sawtooth, pulse), buffer size, number of harmonics, and frequency of the signal.

A SignalGenerator class is defined to generate the reference signals for the speaker and a lock-in amplifier. Attributes of a SignalGenerator object include transmit wave types (square, triangle, sawtooth, pulse), buffer size, number of harmonics, sample rate and frequency of the signal. After the constructor creates a SignalGenerator object, the initializer precomputes one second of the signal (e.g. if the sample rate is 44k, 44k samples are computed) with a Fourier synthesizer module, and maintains a current index pointer which starts from zero and would later be incremented and iterate through the one-second signal to generate each buffer of the reference signal.

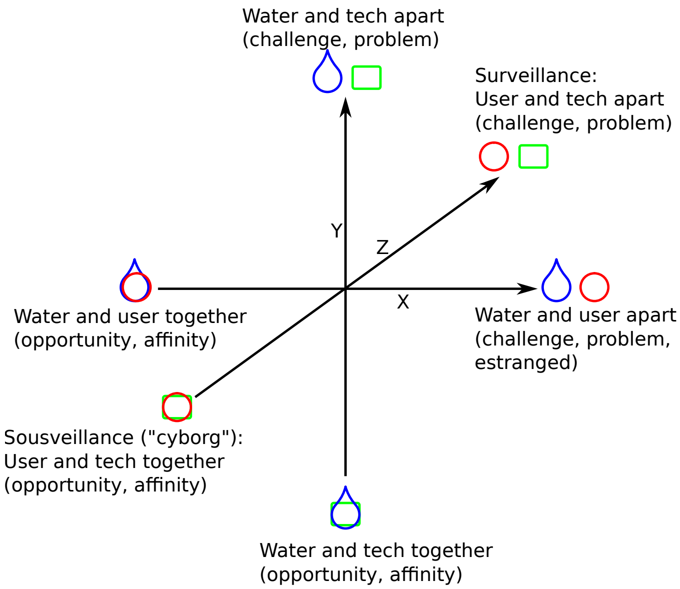


Figure 13. Consider three axes that provide a spatial taxonomy/ontology/classification of WaterHCI systems, efforts, and research directions as follows: Each axis denotes the proximity, affinity, opportunity, etc., at one extreme, versus the challenges, problematization, estrangement, or distancing (i.e. as the elements are further divorced from one-another) at the other extreme. Each axis pertains to two of the three elements, thus there are $\binom{3}{2} = 3$ axes which divide the taxonomy/ontology/classification space into $2^3 = 8$ octants.

The app works with portable or built-in speaker/microphone or external hydrophones. The speaker plays the data that was pushed into an AudioTrack object and microphone data is read from an AudioRecord object. The simultaneous playing and recording work on a single thread which is less computationally expensive and more reliable than a syncronized multi-threaded implementation: in each iteration of the main loop, a buffer of data was pushed into the AudioTrack object and a buffer was read from the AudioRecord object before being processed by the lock-in amplifier.

Software-based lock-in amplifier: A lock-in amplifier is implemented in software and detects the phase difference between the reference signal and the received signal. In each iteration of the main loop, the lock-in amplifier multiplies the reference (e.g. what's fed to the speaker) buffer data with microphone buffer data, and low-pass filters the product, which is then displayed by the SWIM.

SWIM: The phase difference determined by the lock-in amplifier is displayed by setting the coordinates of one or two dots on the screen. In the real mode, the y-coordinate of the dot is set to the phase difference between the received signal and the real reference signal. In the complex, or Argand-plane mode, the y-coordinate of the dot is set to the phase difference between the received signal and the real reference signal and the x-coordinate is set to the phase difference between the received signal and the imaginary reference signal. In a complex2 mode, the y-coordinate of the green dot is set to the phase difference between the received signal and the real reference signal, and the y-coordinate of the green dot is set to the phase difference between the received signal and the imaginary reference signal. In order for the dots to fit on the screen, their coordinates are normalized with the height of the screen, and a recentering technique is employed. The dots are centered by holding the speaker and microphone toward free space and double tapping on the screen. When the phone is held toward free space, it's assumed there's nothing bounced back and the microphone data is what the microphone receives from the speaker, and its phase is considered the background phase to be removed. Upon double tapping, the phase is recorded and is deducted from following calculations of phases.

The SWIM simulator (SWIMulator™) is shown in Fig 14.

4. The future of WaterHCI

Last year Prof. Park of Stanford presented the smart toilet and in less than 4 months this project has moved forward at an amazing pace as the world's most advanced toilet, providing an example at the nexus of water conservation, human health, and technology. The toilet can detect CoViD symptoms and provide personalized healthcare. See Fig 15.

Some exciting developments are in-the-works in the area of creating architectural spaces for water-human-technology interaction.

We are at a pivotal era where we can bring smart technologies to waterfront communities to create better ways to interact through the medium of water.

Human life relies on a supply of clean drinking water, and the work of SwimDrinkFish emphasizes that the best way to protect our drinking water is to swim in it. Swimming in the water raises awareness of the need to combat pollution. Cities like San Francisco have stairs every 400m or so along their busy shipping port so that people can walk down into the water to swim. Canadian cities like Kingston Ontario have recently installed a swimming pier that is open for use 24 hours-a-day.

An exciting development at Toronto Waterfront will bring us a wonderful urban beach together with wave sculptures suggestive of mathematical Fourier (sine and cosine) series. See Fig 16.

Another exciting project is the redevelopment of Ontario Place in Toronto. Presently we have one very nice beach here, a pebble beach, providing wonderfully crystal-clear water that is free of sand, grit, grime, etc. which makes for creation of wonderful underwater pictures, videos, and even a music video, Time, by Monique Barry, filmed by Dan Bowman. However the beach becomes very crowded in the summer months. The new Ontario Place development comes with the suggestion of creating an additional beach to the West, where presently there are very inhospitable rocks. A second beach would increase the capacity for increased bather load during busy summer months. Three new islands are also proposed for people to swim or paddle out to, and this would further increase the bather capacity at Ontario Place. See Fig 17. Ideally we would like to see at least four beaches, as per the original Ontario Place plan (Fig 18).

Another ongoing project is the smart towfloat. A towfloat (also known as a swim-safety buoy) is a typically brightly-colored visibility marker that helps make swimmers more vis-

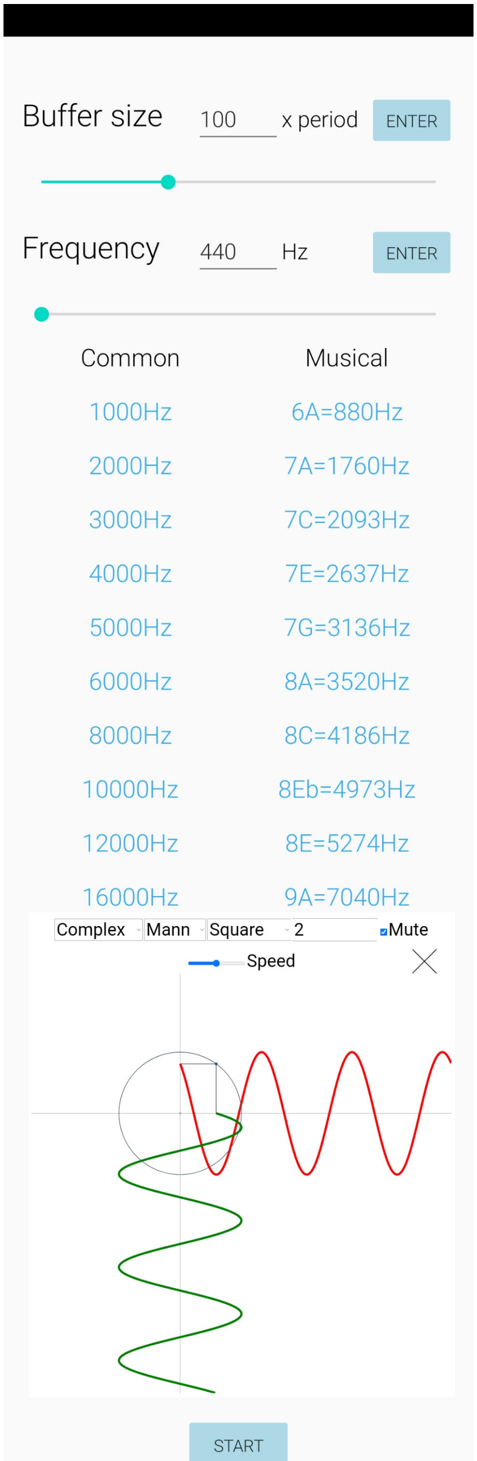


Figure 14. The SWIM simulator (SWIMulator™) app turns nearly any waterproof Android smartphone into a sonar and interactive XR (eXtended Reality) sonar teaching environment. The sonar can work in air, water, or even in sending sound waves through solid matter.

ible so as to reduce likelihood of boat collisions. Additionally many towfloats have a dry cargo compartment so that swimmers can place valuables such as keys, wallet, and smartphone in the float and tow these items along behind them.

The smart towfloat can also take the form of a smart buoy to be used by divers, as a surface flotation device that carries a set of sensors, radio, sonar, transceiver (transmitter/receiver), etc.. The underwater source uses sonar (underwater sound waves) or a wired connection to communicate with the surface device. The surface device then uses radio signals to establish an Internet connection. radio signal to the receiver. Since the device is floating on the water surface, it does not need to be directly placed over the underwater source.

The implementation of such devices can aid the communication between submarines and aircraft. As the relay does not need to be on top of the submarine, the submarine's location remains hidden even if the relay is intercepted.

In the case of divers, they typically already have a diver marker buoy to mark their location. We simply integrate the relay device in the buoy. With the tethered line to the diver. We then use the line as a high-speed data connection between the diver and the float instead of using sonar for that data communication.

5. WaterHCI for safety

Many developments in WaterHCI have been directed at safety. For example, the SWIM (Sequential Wave Imprinting Machine), invented in Ontario, Canada, in 1974, makes visible the otherwise invisible underwater sound waves of sonar or the radio waves of marine radar [6].

The history of marine radars dates all the way back to 1946, when the first commercial marine radars were introduced with their own cabin and roof-mounted scanner [14]. The marine radars are designed to detect objects from far away and depict the distance and location relative to the ship. This information is normally displayed as patterns around concentric circles on a screen with the vessel being the center of the circles. These graphs are normally refreshed with a fixed interval to update the information. This method of displaying information is perfect for the sole purpose of object detection. However, the underlying information that is also gathered in the process such as polarization of the antenna, operating frequency of the system are hidden and discarded, which could also provide useful deductions of the surrounding environment.

In 1990, Simon Haykin proposed the idea of radar vision, which is to make radar an intelligent remote sensing device that is capable of cognitively detect its surrounding environment [15]. This notion broadens the role marine radar plays from only sensing an object with no prior information to possibly portraying a trajectory of such objects' relative movements to the vessel. Haykin also proposed that the system could vary some of its operating parameters such as the polarization or operating frequency to exert influence of its own to its measuring environment. Hence, the radar is transformed from a mere "listening" device to a device that is actively "viewing" its surrounding environment.

5.1. Growler (iceberg fragment) detection

The chirplet transform (also invented in Ontario, Canada) was invented originally to detect small iceberg fragments called growlers, for the safety of vessels navigating in ice-infested waters [10]. This work was based on the observation that the

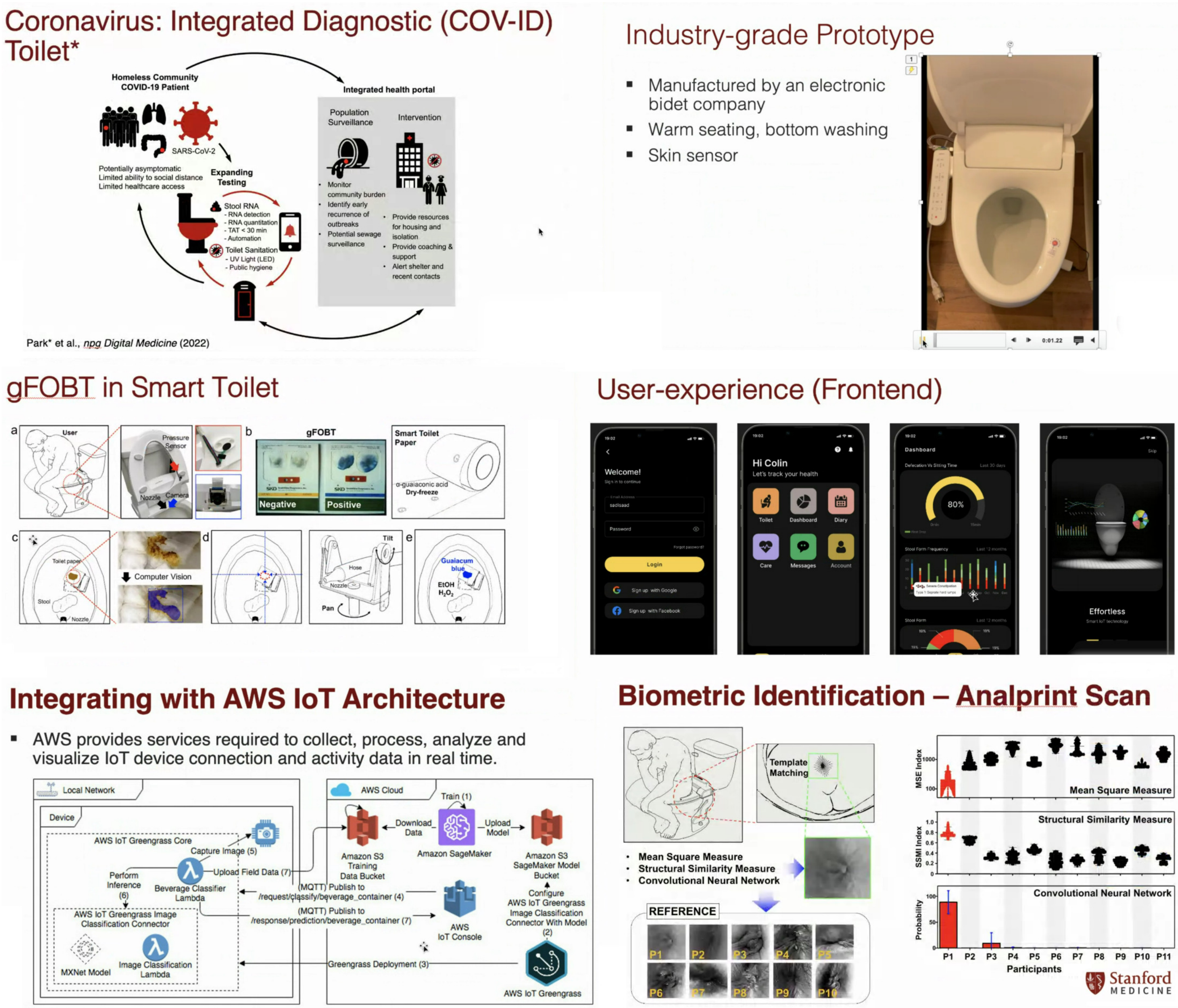


Figure 15. Some recent advancements on the Stanford smart toilet project were presented this year at WaterHCI-2022 for the first time. The toilet can diagnose symptoms of CoViD and other diseases and provide automated personalized health care while conserving water.

Doppler returns from ice fragments were "chirpy" in nature, i.e. represented time-varying frequency (pitch) changes. For example, while listening to the sounds of Doppler radar signals, from growlers, one can hear what sounds vaguely like bird song, especially like the birds known as warblers, thus suggesting that spectral analysis (Fig19) is less-than-optimal since the frequency of what we are trying to sense is constantly changing. This work falls under the new discipline of radar vision [18].

A note on terminology:

- Ice floe: 20m to 10km across;
- Iceberg: > 15m long;
- Growler < 1m high, < 5m long.

5.2. Growlerboarding: Paddling on growler-sized ice fragments

The scope of WaterHCI can be broadened to include not just water, but also H_2O in other states-of-matter such as ice.

Growlerboarding™ or Growlering™ is standing on growler-sized ice fragments while paddling. It is an activity that celebrates vessular precarity, i.e. the notion of an ephemeral vessel or MVV (Minimum Viable Vessel) [19]. Most notably, growlerboarding often becomes icewater swimming for the most part, as the ice breaks up, or suddenly becomes insufficient in its buoyancy to support the weight of the one or more people upon it. Safe practice of growlerboarding is based on key principles such as never swimming alone, always having support, and having the right systems in place.

Icewater swimming in general is a great form of safety train-

Figure 16. Existing WaveDeck sculpture (upper left) creates a fun playful waterfront space. Future expansion of Waterfront Toronto includes the Parliament Street Slip complete with a new WaveDeck and outdoor pool right next to the lakefront.

ing, so that if one were ever to fall into icewater, or to fall through the ice, the sense of familiarity with this world could save one's life. In this way growlerboarding is a form of safety training.

Growlerboarding can also take the form of an augmented reality exertion-game or exergame (exercise game) at the intersection of ice, water, humans, and technology (fig:20).

To advance the fun and sport of growlerboarding, we developed a smart SUP (Stand-Up Paddling) paddle into which was integrated a SWIM (Sequential Wave Imprinting Machine). See Fig 21.

5.3. The Smart Beach Project

An exciting new project coming to Ontario is the Smart Beach Project from University of Windsor in collaboration with Bruce County, and the Municipal Innovation Council (MIC).

Our Great Lakes contain approximately 84% of North America's freshwater (approx. 21% of the world's freshwater supply). Ontario, Canada, is also home of the world's largest freshwater lake.

Unfortunately, though, about 50 people drown each year in the Great Lakes. We really don't have a good understanding as to when and how those [beach] hazards develop and how do we better provide safety messaging to beach users. A network of sensors will be deployed at Kincardine's Station Beach to monitor water levels, waves, water currents, and pedestrian and swimmer movement. The Smart Beach Project will automatically advise beach-goers which sections of the beach are safer, which sections of the beach are more hazardous and when various conditions occur.

Surf-related drowning fatalities are an emerging public health issue in the Great Lakes and represent a significant economic burden to the Province of Ontario. Most public beaches in Ontario do not have lifeguard programs and there is a lack of active monitoring of surf conditions to provide real-time warnings. Working in partnership with Municipality of Kincardine and Bruce County, we are implementing an integrated sensor network to provide real-time measured and locally calibrated risk and hazard forecasts for beach users and managers to promote beach safety. The integrated sensor network will include surf and beach activity cameras, meteorological stations, in-situ water level and wave sensors, and traffic and pedestrian sensors. The surf hazard thresholds (red, yellow, green) will be based on local knowledge of surf conditions through a series of community-based workshops, and the risk assessment will be completed in consultation with first responders and beach managers based on predicted and measured surf conditions and real-time monitoring of beach user activity. The locally developed surf hazard warning and forecast will be made available through a progressive web app that will include a gamification strategy to incentivize safe beach activity and support geographically based hazard warnings as necessary. The hazard forecast

Figure 17. A bold and exciting new proposal from Therme Canada to build an additional beach and wellness facility at Ontario Place, along with an upgrade to the existing Ontario Place West Channel swim pier and breakwall.

will also support the placement of dynamic warning signs at primary access points and on the test beaches. Beach user surveys and remote tracking will be used to determine if and how visitors respond to the hazard warnings and the effectiveness of different communication and incentive strategies, and whether beach access design strategies could further promote safe beach

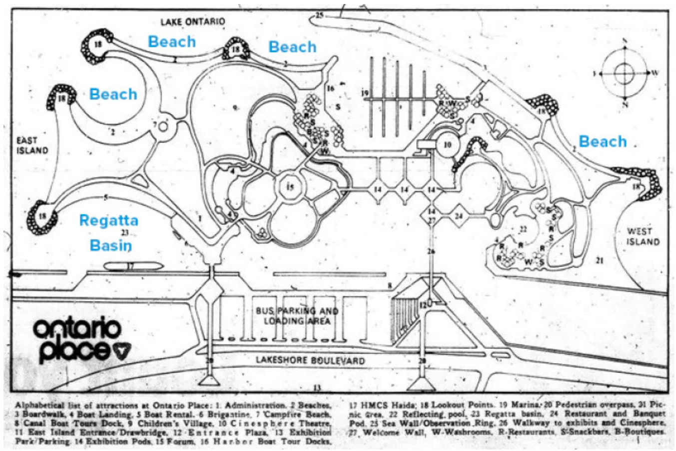


Figure 18. "Maps of the original Ontario Place show four areas that were designated as beaches." [13]

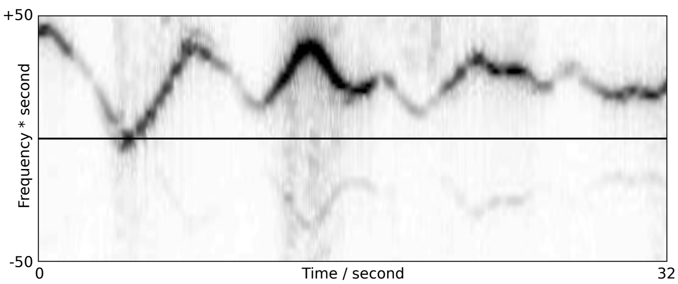


Figure 19. Time-Frequency distribution from Doppler radar return of a growler (iceberg fragment) [10, 16, 17]. Note the wavy line in time-frequency which indicates a periodically-varying frequency shift called a "warble". The chirplet transform (and in particular the warblet transform) was invented for WaterHCI-based marine safety [10].

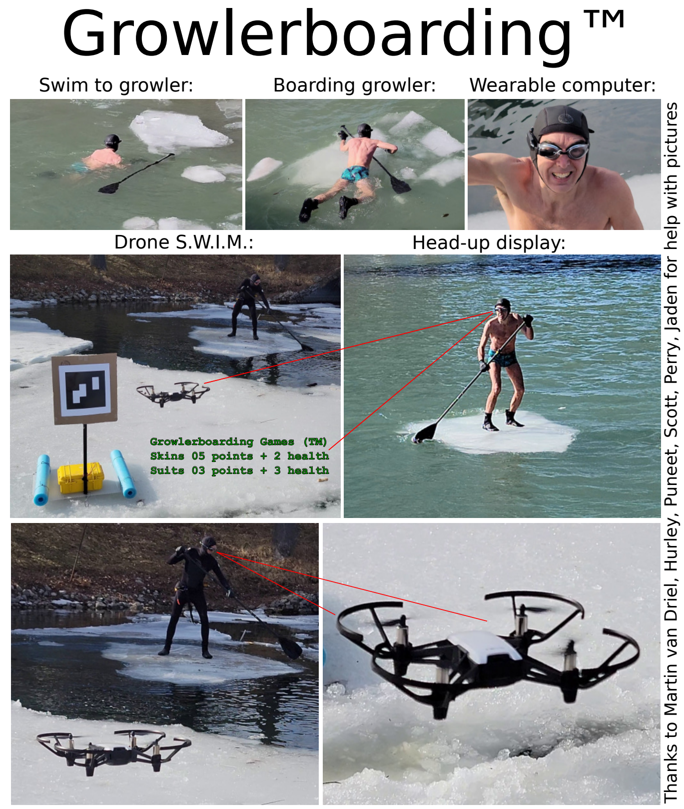


Figure 20. Growlerboarding is the boarding of a growler-sized ice fragment, often to stand on it and paddle through the water. Growlerboarding usually involves icewater swimming to get to the growlers, or when they cease to become viable vessels (e.g. as ephemeral vessels one simply swims to the next viable vessel). Growlerboarding can also take the form of an augmented-reality exercise game.

use. The results of this research will lead to an adaptable and scalable approach to improve beach safety in the Great Lakes through real-time monitoring and warnings that promote direct and indirect changes in beach user activity.

Other applications of the Smart Beach Project include automatic ripcurrent detection based on a deep understanding of ripcurrents [20–22] (Fig 22.

Other related technologies include the Smart Buoy Project at Ontario Place [23] which feeds into the Swimguide of Swim Drink Fish [24].

5.4. Ellis Aquatic Vigilance System (EAVS)

The Ellis Aquatic Vigilance System (EAVS) integrates analytics, artificial intelligence and end-to-end monitoring under and above water and on land to elevate swimmer safety, drowning prevention and security. EAVS can see what lifeguards may miss due to the number of guests, environmental conditions and other factors [25]. See Fig 23. EAVS is at the intersetion of humans and AI (Artificial Intelligence) in an aquatics environment, i.e. at the intersection of water, humans, and technology:

- AI video analytic system views activities, and provides alerts for undesired behaviors;
- Certified operators scan live feed for potential problems, providing rapid response;
- System aggregates video surveillance, radio communication, geopositioning, and incident management reporting.

Future installations include lagoon and beach-like settings.

Moreover, automated computer-based drowning detection is an additional area of recent research and development [26].

5.5. Drone-based WaterHCI

. Drones have been proposed for shark detection, drowning detection, surveillance, and many other applications [27–29].

We also propose drones as a more direct form of WaterHCI in regards to SWIM (Sequential Wave Imprinting Machine), i.e. interacting directly with marine radar, sonar, and the like, and understanding the waveforms of the water. In this way we attempt to realize the potential of the TeachBeach principle in making an educational and fun aquatic play lab.

In addition to the smart SUP paddle, drones were used as a more modular and compact method of displaying the waveform of the Doppler shift of radio waves or sound waves (radar or sonar) received by a radar or sonar system. This early iteration of the system builds upon research done in [30] and

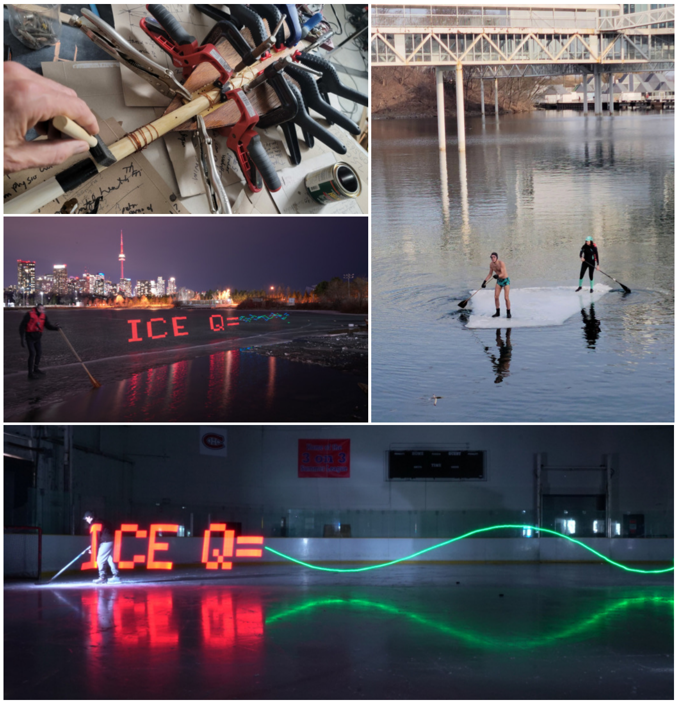


Figure 21. Custom-made smart SUP paddle with integrated SWIM (Sequential Wave Imprinting Machine) for the Ontario Placemaking Project, and smart hockey stick, for ice research in sensing and meta-sensing using sonar and marine radar.

Figure 22. Smart Beach Project coming to the Great Lakes of Ontario. Automated rip current detection is one important aspect of the research. We also need to consider safety at piers, especially given the fact that many swimmers love the thrill of jumping from a height such as that afforded by a pier. This underscores the need for providing safe swim piers and jumping platforms.

applying it to WaterHCI. Drone swarms were used for both metasensing (sensing of the capacity of sensors to sense) for various sensors on an electric, semi-autonomous vehicle as well as to autonomously sense and visualize electric field distributions around overhead power lines for ease of inspection and maintenance [31].

In WaterHCI applications, a single drone can be made to hover above a growler upon which is placed a marine radar system whose output is wirelessly transmitted to a ground control station which then uses the output to control the drone's altitude (Fig 20). This provides a vital step in making another aspect of water-human interaction (growlerboarding) more easily accessible to all, and providing insight such as ice quality, balance, movement, etc., to help a "boarder" learn how to balance on the ice. Unlike SUP (Stand-Up Paddleboard), the ice can tip in any direction not just mainly left-to-right, so balancing skills are required in all directions not just primarily left-to-right.

The real signal doppler shift output was measured using a keysight U1242c handheld digital multimeter which was connected to the USB port of a Raspberry Pi via the provided infrared-to-usb cable. The U1242c was chosen due to its compactness as well as the fact that it's compatible with VISA (Virtual instrument standard architecture), an API created by Keysight which allows wired communication between one's device and any supported measurement instrument using a number of wired interfaces, including serial.

In this case, the python implementation of VISA was used to create a VISA resource manager object and open a session with the aforementioned multimeter over an open serial port to both send it commands and receive data. A python script was written on the aforementioned Raspberry Pi to trigger the instrument(obtain current analog input value) and read its digital outputted value once every 30 milliseconds(maximum trigger rate for the U1242c).

As the radar was mounted to the growler and the ground control station needed to be on shore to reduce load on the growler, communication between the Raspberry Pi and the ground control station needed to be wireless. To accomplish this, the python extension of bluetooth(PyBluez) was used to create a wireless server with the Logical link control and adaptation protocol(L2CAP), a higher layer of the bluetooth protocol stack which allows one to create a server socket, bind it to a specified address and send data packets to any client connected with an Asynchronous Connection-Less(ACL) link. Thus on the server side, once a UDP connection was established at said specified address over a specified port, the script ran a constant while loop the request the current output value from the multimeter, send it as a data packet to the client(ground control station) whereupon said value is converted to a string and stored in a text file to be used as a setpoint for the drone on the vertical axis.

Our positioning system was implemented using a single Ryze Tello drone and an Aruco marker.

Aruco markers are synthesized binary fiducial markers very easy to detect by computer vision systems due to their high contrast. A python script was then written to detect the marker using the Tello camera which, upon connecting to the UAV and sending the takeoff command ran a constant while loop grab-

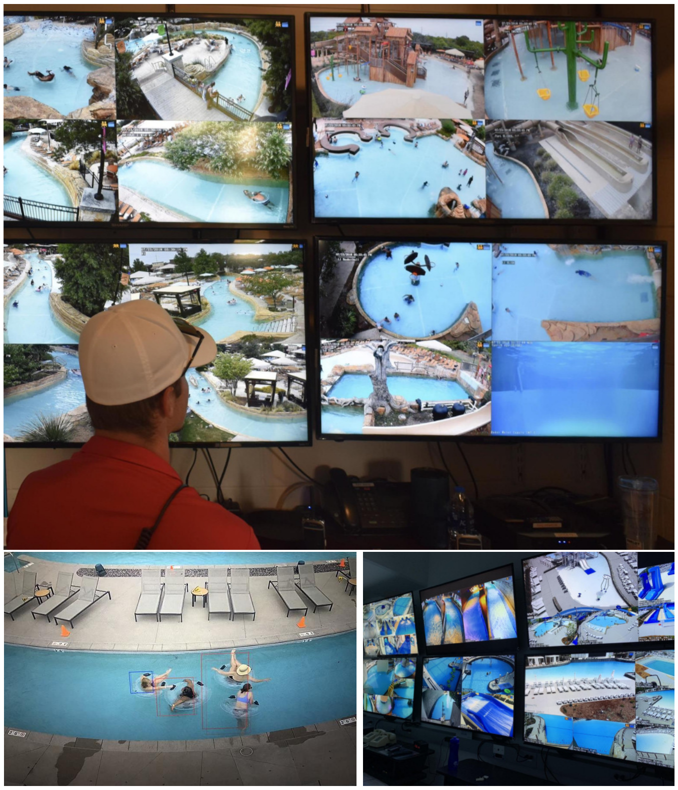


Figure 23. Ellis Aquatic Vigilance System (EAVS) integrates analytics, artificial intelligence and end-to-end monitoring under and above water and on land to elevate swimmer safety, drowning prevention and security [25].

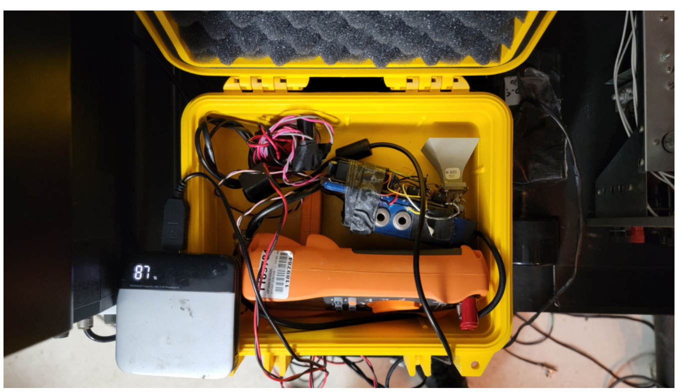


Figure 24. Image showing waterproof box used to house radar set(upper right corner), USB battery for radar(bottom left corner) and multimeter for analog to digital conversion(bottom right corner)

bing the current frame from the camera using the Tello's built-in frame grab method then finding the marker's position and dimensions in frame using OpenCV2's aruco library.

A 4x4 resolution, 22x22cm marker was printed and laminated in order to allow use in the case of the growler sinking or submerging, then mounted upon a portable base which held the marker approximately 1m above the ice's surface while also holding the container for the radar, multimeter and raspberry pi set as shown in 24.

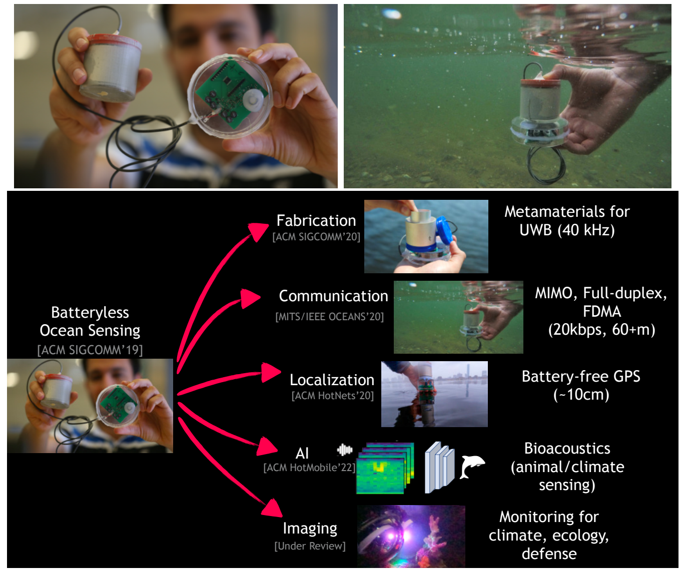


Figure 25. Underwater Internet of Things node in the Atlantic ocean.

Once mounted to growler, drone was placed approximately 2m in front of marker while paddler mounted smaller growler behind the marker in a location where movement would be picked up by radar set through waterproof box. Real component of the doppler radar return was then wirelessly transmitted to ground control station, amplified by a factor of 3 and saved to the y axis setpoint txt file to be used as a setpoint for the drone on the vertical axis. Drone was then made to hover 1.7m in front of marker while remaining centered on the x axis. The paddler began several metres out, then paddled a smaller growler towards a larger growler upon which drone and radar were stationed to obtain data to display.

6. Bringing the Internet of Things to the Underwater World

Bringing massive connectivity to low-cost, low-power ocean sensors is important for numerous oceanographic applications (across climate/weather modeling, marine biology, aquaculture, and defense). However, standard IoT technologies (e.g, Bluetooth, WiFi, GPS) cannot operate underwater, which has left 70% of our planet (the ocean) beyond their reach. Research is changing this reality through the invention of IoT technologies that are inherently designed for the ocean. Specifically, we need to rethink the entire IoT technology stack in the context of oceans, to provide low-cost (< $100), net-zero-power, scalable connectivity technologies that seamlessly operate underwater and pave the way for massive underwater sensing, networking, localization, imaging, and machine learning (Fig 25). The work being undertaken at MIT in this area [26] is of great importance to the WaterHCI community.

7. Marine radar designed for interactive WaterHCI

Ongoing research is being directed toward WaterHCI-specific radar systems useful for teaching, fun, and interactive elements of WaterHCI together with SWIM.

The SWIM is often used to depict outputs from a radar system which makes it the perfect demonstration of a radar vision system. Instead of showing just a radar plot of concentric circles and dots, the SWIM portrays the waves that are received by the radar and illustrates the Doppler shift that is caused by the surrounding objects which makes it capable of sensing its environment. Its luminescent nature of depicting such Doppler shift also made it possible for the human eye to see a trail of such phenomenon rather than segmented points along the waveform which makes the SWIM a device, combined with the human mind, capable of memorizing prior information. The self-explaining nature of the SWIM makes it an intuitive instrument to be used for expanding the sensory capability of human and can be incorporated alongside the human mind to constitute the modern day "waterborgs" (aquatic cyborgs).

7.1. Methodology

7.1.1 The real-only lock-in

The SWIM principle relies on phase-coherent detection to perform properly to display "sitting waves". Here we consider the case where we generate and transmit the reference signal locally on the device. The reference signal, $f_{ref}(t)$, generated could be described as follows:

$$f_{ref}(t) = Asin(\omega t) \tag{1}$$

The received signal could be considered as the transmitted signal with an attenuated amplitude and a phase shift, which could be expressed as follows:

$$f_{rx}(t) = \alpha \cdot Asin(\omega t + \theta_{rx}) = \alpha \cdot Asin(\omega t + x) \tag{2}$$

In Eq.2, α is the attenuating factor, and θ_{rx} is the phase shift between the received signal and the transmitted signal.

By multiplying the two signals, we gather the following:

$$\begin{aligned} f_{rx}(t) \cdot f_{ref}(t) =& \alpha Asin(\omega t + x) \cdot Asin(\omega t) \\ =& \frac{1}{2}\alpha A^2[cos(x) - cos(2\omega t + x)] \end{aligned} \tag{3}$$

Note that the second term in the outcome of Eq. 3 is typically filtered out by a low-pass filter to leave us with a term that is only a function of x. This means that the output of the lock-in is only a function of the relative position of the receive antenna, i.e. the "sitting wave" effect of SWIM which basically shears the spacetime continuum in such a way that the speed of wave propagation, i.e. the speed of light (our sound), is zero. This creates the augmented reality (or more precisely, the eXtended reality, i.e. XR).

In a traditional lock-in configurations, the signals represented by Eq. 1 and Eq. 2 alone would suffice for the need to do phase-coherent measurement and detection. This also constitutes the fundamental principle behind a traditional radar which measures the speed of the object. However, a radar vision system should be able to actively "sense" its surrounding environment, which implies that a system that should be able to acquire more than just the speed about the surrounding objects. In light of this assumption, the direction of motion of the object would be another interesting aspect of the surroundings that should be sensed by the system. This information requires the usage of a complex lock-in system.

7.1.2 The complex lock-in

A complex lock-in, compared to the traditional lock-in, requires an in-phase and an quadrature reference signal rather than the single real reference in the real-only lock-in configuration. Albeit the extra reference signal, the transmitted signal in the system is still a real signal which can be described as $f_{tx}(t) = Asin(\omega t)$.

However, the complex lock-in system will generate two real-valued reference signals that are 90 degrees out of phase to each other. We denote the two components as in-phase(I) and quadrature(Q), denoted as $f_I(t)$ and $f_Q(t)$:

$$\begin{aligned} f_I(t) &= \alpha_{ref} \cdot Asin(\omega t + \theta_{ref}) \\ f_Q(t) &= \alpha_{ref} \cdot Acos(\omega t + \theta_{ref}) \end{aligned} \tag{4}$$

We use α_{ref} to denote the amplitude variation associated with the complex reference generation and θ_{ref} to denote the possible constant phase shift between the input, which is coupled from the transmission signal, and the output, which is the generated reference signal.

Similar to the multiplication performed in Eq. 3, we can multiply each reference signal with the received signal to get our complex output:

$$\begin{aligned} f_{rx}(t) \cdot f_I(t) &= \alpha_{ref} Asin(\omega t + \theta_{ref}) \cdot \alpha Asin(\omega t + \theta_{rx}) \\ &= \frac{1}{2}\alpha\alpha_{ref}A^2[cos(\theta_{ref} - \theta_{rx}) - cos(2\omega t + \theta_{ref} + \theta_{rx})] \\ &= \frac{1}{2}\alpha\alpha_{ref}A^2[cos(\theta_{rx} - \theta_{ref}) - cos(2\omega t + \theta_{ref} + \theta_{rx})] \\ &= \frac{1}{2}\alpha\alpha_{ref}A^2[cos(x) - cos(2\omega t + \theta_{ref} + \theta_{rx})] \end{aligned} \tag{5}$$

$$\begin{aligned} f_{rx}(t) \cdot f_Q(t) &= \alpha_{ref} Acos(\omega t + \theta_{ref}) \cdot \alpha Asin(\omega t + \theta_{rx}) \\ &= \frac{1}{2}\alpha\alpha_{ref}A^2[sin(\theta_{rx} - \theta_{ref}) + sin(2\omega t + \theta_{ref} + \theta_{rx})] \\ &= \frac{1}{2}\alpha\alpha_{ref}A^2[sin(x) + sin(2\omega t + \theta_{ref} + \theta_{rx})] \end{aligned} \tag{6}$$

Similarly, we can filter out the higher frequency component with a low-pass filter as described in Sec. 7.1.1.

The complex output (i.e. the two real outputs) can be denoted as the in-phase and quadrature outputs, which can be used as coordinates for a polar coordinate system, i.e. the Argand (complex) plane. As an object such as a growler is moving toward or away from the radar, a point in the Argand plane (e.g. pictures as a dot on an oscilloscope set to X-Y plot mode which can be implemented in the eyeglass head-up display, for example) as a plot of the in-phase versus quadrature output, will be spinning counter-clockwise (positive angle) when the growler approaches the radar, and clockwise when it is moving away. This establishes an association between the dot's spin and the direction of the object's movement and distinguishes the complex radar system from a traditional marine radar.

This system forms a fun way to teach complex numbers, mathematics, phase-coherent detection, and physics, using fun and frolic in an aquatic play setting.

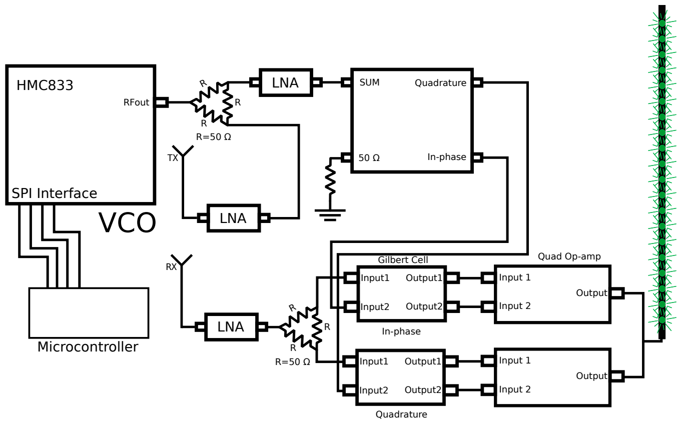


Figure 26. The SWIM device configuration. The LED strip on the right is the SWIM for visualizing the waveform received by the RX antenna

7.2. The SWIM apparatus design

The SWIM apparatus requires a device capable of lock-in detection to properly display the intended waveform. Similar to a lock-in amplifier, a common SWIM device can be broken down into three parts: a referator, which handles the generation of the reference signal, a mixer, which mixes the incoming receive signal and the reference signal, and a display device, which would commonly be a bar of Light-Emitting Diodes(LED) for SWIM to display the final waveform.

7.2.1 The Referator

A ultra-wideband Phase-Locked Loop(PLL) with integrated Voltage Controlled Oscillator(VCO) is used to generate the reference signal. The HMC833 is a PLL with integrated VCO manufactured by Analog Devices that can handle $25\,\mathrm{MHz}$ to $6\,\mathrm{GHz}$. The chip could communicate with any compatible micro-controller through a 4-wire Serial Peripheral Interface(SPI) for configuration of various settings including output frequency, Vtune step size, etc. The micro-controller runs a program to infer the correct register values to generate the required frequency for the reference signal on the PLL and handles the communication with the chip.

The reference signal is generated and split through a Delta resistive power divider for transmission and quadrature generation. The Delta resistive power divider is chosen for its wideband response and its minimal footprint over the Wilkinson power divider albeit its advantage of transfer loss.

We denote the two outputs from the divider as Reference(Ref) and Transmission(TX) for ease of discussion. The Ref output is fed into a wideband quadrature phase splitter to generate the in-phase and quadrature components of the reference signal for the mixer section. Both outputs were amplified with a LNA(Low Noise Amplifier) to compensate for the low peak-to-peak voltage output of the VCO with its minimum being $178.223\,\mathrm{mV}$.

Recent research has shown that it is possible to design quadrature hybrid passive components for excellent wideband response [32], which provides a reliable and simple method to generate quadrature signals from a real signal input for lock-in detections. In our setup, we chose a 90-degree hybrid phase splitter from Mini-Circuits to generate the quadrature signals and is connected to the output of the LNA accepting input from the Ref output of the divider network. The 90-degree phase splitter and the PLL constitutes the referator section of the SWIM device.

7.2.2 TX configuration

On the other side, the TX output of the divider network would undergo an LNA topology identical to the Ref path, whose output would be fed into a SMA female connector that is connected to a stationary antenna to serve as the reference transmission antenna which broadcasts the reference signal that will be picked up by the receiving side of the lock-in detection device.

7.2.3 RX and mixer configuration

The receive antenna would be connected to another LNA whose output is connected to two identically configured gilbert cells. These two gilbert cells would multiply the in-phase and quadrature reference signals separately with the outputs from the LNA to generate the lower frequency component, which serves as the output to depict the waveform, and the higher frequency component, which is filtered out by the final steps of signal processing.

The outputs from the Gilbert cells are processed by a quadruple op-amp configuration to provide the extra gain required to demonstrate the smooth transition of the waveform on the final plotting device. This constitutes the baseband gain stage of the SWIM device.

The setup was built and tested at Echo Beach at Ontario Place, owing to its being Toronto's best location for ice fragment formations. Many unique kinds of ice form in Brigantine Cove, a bay in Toronto, Ontario (elevation 81m) metres, in the part of the cove that adjoins Echo Beach.

The idea of making a fun and playful research lab at Ontario Place – "Ontario Placemaking" has served to teach many important principles of ice formation and ice studies while having fun doing this important research.

8. Summary and Conclusions

Water-Human-Computer-Interaction/Interfaces (WaterHCI), a field that originated in Southern Ontario in the 1960s and 1970s, is gaining widespread acceptance and adoption, and we have highlighted the importance of WaterHCI to Ontario and to the world as a whole.

We envision Hydraulikos as a combination of a beach, wellness spa, research lab, and a university or school for researching and teaching and being taught by people of all ages and backgrounds, including Indigenous ancestral teachings on water. We hope to develop concepts and features such as the research and teaching platform (Educational Swim Pier) that is also fun and playful, as illustrated in Fig 2, and expand around the philosophy of LBB (Learn-By-Being) to reach people of all ages, cultures, and backgrounds with water as a universal medium of human engagement and Web 3.0 + IoTTT computation.

We have established Ontario Place as a location for world-class research, teaching, scientific exploration, and fun and frolic.

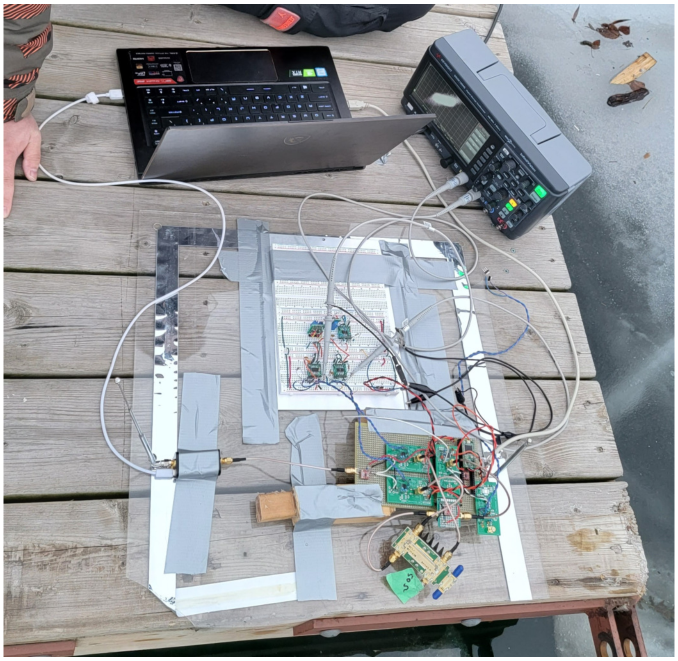


Figure 27. The experimental configuration using the SWIM apparatus as described in Sec. 7.2. The SWIM apparatus rests on a single piece of acrylic board as shown in the picture. The antenna on the bottom left of the picture is the RX antenna, and the TX antenna is horizontally to the rightmost side of the acrylic board. An ice fragment is moved on the left side of the RX antenna at Echo Beach at Ontario Place where many unique kinds of ice form.

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