WaterHCI Part 2: Open water sensing, meta-sensing, and observing with drones and augmented reality

Steve Mann, Zhao Lu, Faraz Sadrzadeh-Afsharazar, Christina Mann, Samir Khaki and Jaden Bhimani
MannLab Canada, 330 Dundas Street West, Toronto, Ontario, M5T 1G5

***Abstract*—WaterHCI (Water-Human-Computer Interface/Interaction/Intersection) is a new field of research that was introduced in our other IEEE SPICES 2022 paper appearing in this conference Proceedings. In this paper, which comprises Part 2 of this 2-paper series, SWIM (Sequential Wave Imprinting Machine), a WaterHCI tool developed in the 1970s, is applied to understanding physical phenomena in air and water, using drones (uncrewed aircraft or ships) for sensing and meta-sensing (the sensing of sensing), as well as to develop an epistemological framework for understanding the world, such as the world of sensing and sensors, as well as the environment, e.g. beach water characteristics, etc.. In Part 1, a sensor and meta-sensor pod was developed for being towed behind a swimmer to provide immediate augmented reality feedback of the current water characteristics to enable the swimmer to choose an optimal path to swim. In this paper (Part 2), this pod is now also used in the context of an autonomous watercraft developed for towing the pod in a pre-determined or adaptive pattern. Thus an augmented reality "heatmap" is developed that shows spatial variations such as water temperature, turbidity, conductivity, etc..**

***Index Terms*—SWIM (Sequential Wave Imprinting Machine), Augmented Reality (AR), eXtended Reality (XR), Sensing, Meta-sensing, Open water, Water reservoir, Robotics, Autonomous sensing, Digital Signal Processing (DSP)**

I. INTRODUCTION

Webster's dictionary defines "drone" as an uncrewed aircraft or ship guided by remote control or onboard computers. https://www.merriam-webster.com/dictionary/drone

In this paper, SWIM (Sequential Wave Imprinting Machine), a STEM teaching tool, is combined with concepts of citizen science and outdoors education for beach water quality sensing, i.e. to build on our concept of the "Teach Beach™" [1].

Smart water quality sensing has been a popular research topic in recent years [2]. With recent advances in drones, wireless communications, sensing, and imaging technologies, spatially resolving water quality parameters is now becoming increasingly more cost-effective and timely. Water quality parameters such as temperature, turbidity, and chlorophyll-a are measured using thermal, visible, and hyperspectral imaging apparatus on drones [3], [4]. However, such a method only allows for the approximate estimation of such parameters, requires expensive cameras that are not financially suited for the average hobbyist, and require intensive hyperspectral image processing algorithms for the extraction of the desired water quality parameters. Contact water quality sensing is by far the simplest and the most cost-effective method for use by the average citizen scientist. By towing a contact sensor module in a raster pattern, it is possible to spatially map water quality parameters in two dimensions. Raster scans of open water can inform nearby swimmers to accordingly steer their swimming path to avoid harmful patches of water. For instance, through the use of E. coli sensors, swimmers can avoid areas with high E. Coli counts.

Drones are now becoming low enough in cost that an individual swimmer or group of swimmers can use this technology to help ensure their own safety and well-being through sensing and meta-sensing of water and water quality. In this way we can enter the growing world of sousveillance (sensing by individuals or small groups of citizen scientists), rather than relying on surveillance (sensing by governments and large business enterprises).

A. *Sousveillant systems*

Surveillance has been the dominant veillance over the past 200 years or so [5], but technologies of sensing have become more affordable, giving rise to a plurality of veillances. OED (Oxford English Dictionary defines sousveillance as "...observation or recording ... by members of the public, typically using personal devices...". More generally, sousveillant systems are systems that provide a counterpart to "big watching ("big data", big-government, big industry, big-science, etc. in the form of "little watching" (sensing at a more human scale) [6]. In this spirit we seek to develop autonomous technologies that are simple enough for a small group of swimmers to deploy for their own safety and well-being, without having to rely on large infrastructure.

II. EXAMPLE APPLICATION: UNDERSTANDING WATER QUALITY

We propose the use of SWIM to help teach and understand beach water quality assessment. We're interested in understanding the spatial distribution of water quality in various bodies of water in which we swim, so we constructed a simple system to provide realtime epistemological exploration of water at the beaches where we swim: (1) Woodbine beach in Toronto, Ontario; (2) West island beach at Ontario Place; and (3) Kelso reservoir in the Halton region conservation authority; see Fig. 1 and 2.

Although there are official postings of water quality, these tend to be delayed, i.e. from a previous day or week, and they also tend to be just a single number for the whole beach, whereas what we wish to ultimately attain is a realtime understanding of the spatial variations, up-to-the-minute (e.g. plan a safest path to swim based on current conditions). This

978-1-6654-4940-3/22/$31.00 © 2022 IEEE

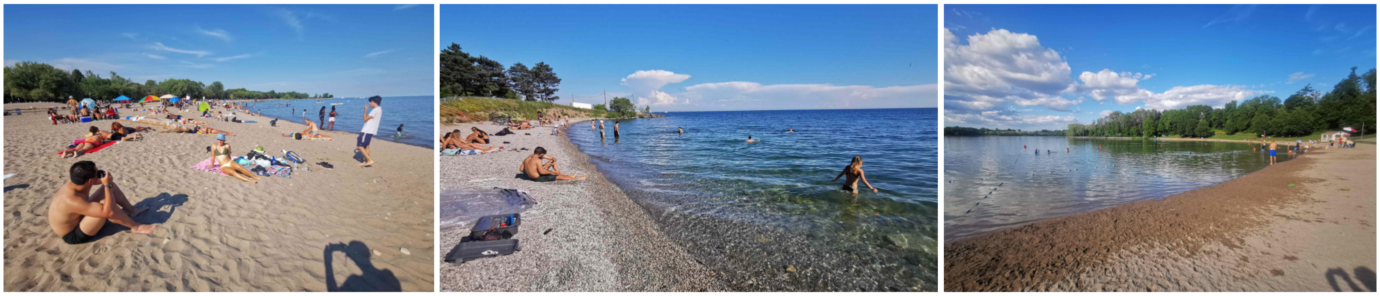


Fig. 1: Subject beaches: (left) Woodbine beach in Toronto, Ontario; (center) West island beach at Ontario Place; (right) Kelso reservoir at Halton conservation authority.

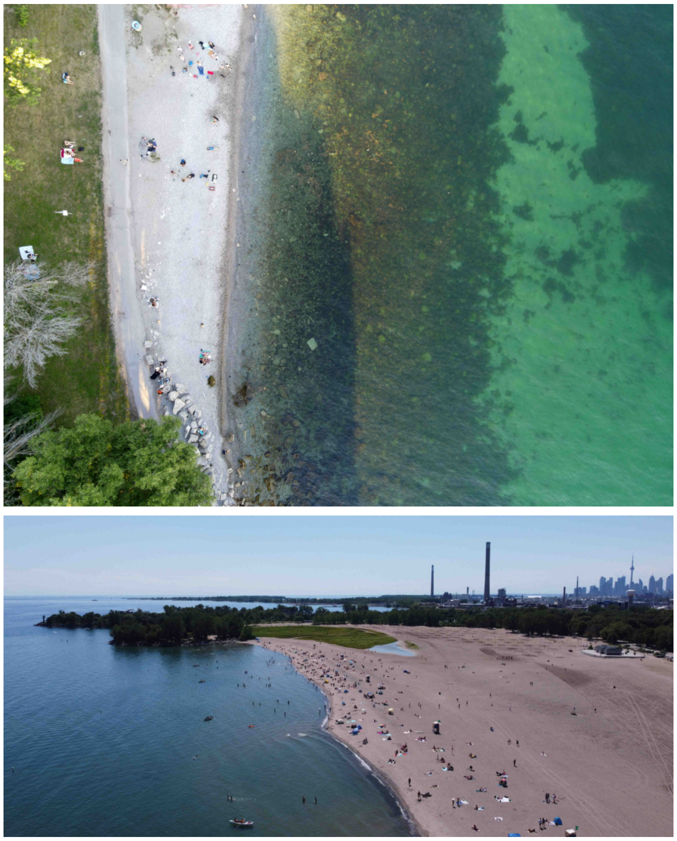


Fig. 2: Drone views of Ontario Place and Woodbine beach.

led us to an understanding of robotics, "making", citizen science, and realtime augmented reality.

III. Goals and objectives

The objective is to develop, explore, and revolutionize open water quality monitoring first through development of a "Smart Pond" system for the Kelso reservoir swimming pond, and eventually deploy our solution for other bodies of water.

Bodies of water have traditionally been analyzed by manual data collection which can be slow, prone to human error, inefficient, and expensive.

We propose to develop an open-source, open-access, autonomous ("waterbot", drone-based, and land-based) water quality "Smart Pond" monitoring platform. It will be fully autonomous and provide real-time, high spatial-resolution sensory information about water quality, and will allow researchers and the public to explore virtual environment maps of the pond. This will help other researchers better understand the pond, as well as help to educate the public about water quality, the environment, and sensing and meta-sensing in general.

The sensor interface builds on Part 1 and will be able to measure water quality indicators, including pH, dissolved oxygen, turbidity, temperature, conductivity, nitrates, phosphorus, optical clarity, and solid particulates, with the additional benefit of autonomy. The system will then generate real-time graphs, environment maps, virtual representations, phenomenological augmented reality overlays, and insights of environmental conditions which will be openly accessible online in realtime to researchers as well as to patrons through their smartphones.

In addition to the contributions of our previous work, this work is superior to existing open water quality sensing methods, for multiple reasons:

- automated data collection decreases labour as technicians no longer need to go into the field
- the spatial resolution of a moving sensor yields far more data points than manual collection
- automation eliminates human error
- minimizes the cost of the sensor system, since a single robot can service a large area of a body of water

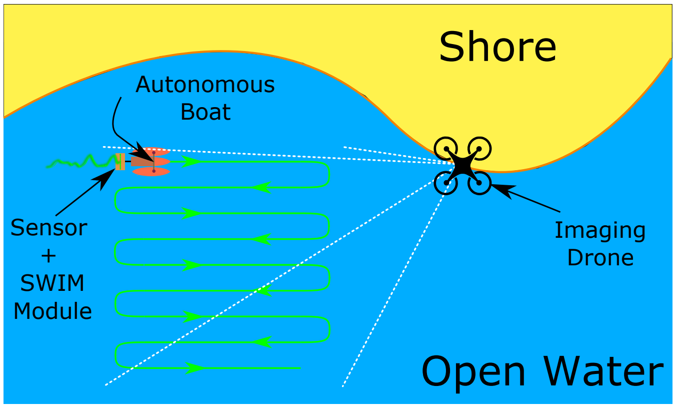
We hope that the proposed system will eventually increase accuracy, lower costs, and improve access to water quality data. These developments are vital, as enhanced understanding of water quality will improve the health and well-being of people, plants, animals, and our environment.

IV. Experimental setup

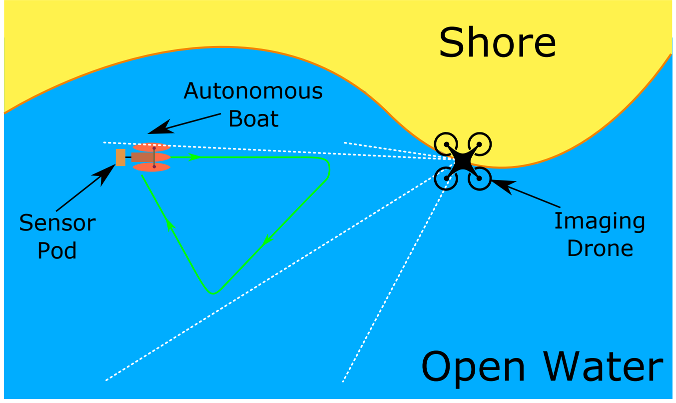
Our setup is illustrated in Fig 3 (towing by autonomous watercraft). The conclusions in Part 1 gave the inspiration for developing an autonomous framework that allows one to capture more data at a consistent, reliable, and controlled rate.

V. Building the autonomous watercraft

The autonomous watercraft was constructed by 3D printing in sections, and assembling the sections, and then tested in a float tank before being deployed on beach sites. See Fig 4 for it's design, Fig 5 for its subsequent printing and assembly and



(a) Raster Scan



(b) Free-Form Scan

Fig. 3: Sensor pod and sequential wave imprinting machine being towed by autonomous watercraft in two patterns: Raster Scan and Free-Form Scan

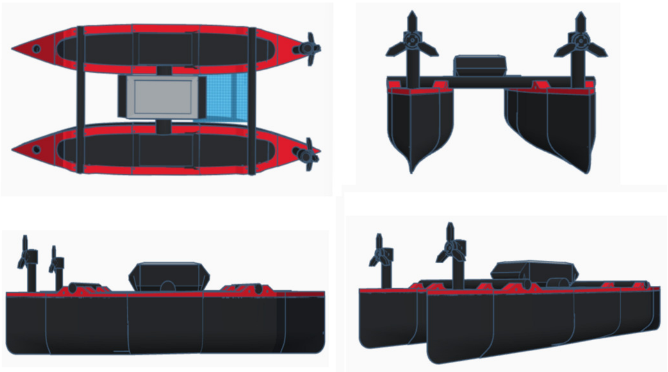


Fig. 4: CAD Design of autonomous watercraft

Fig 6 for the full physical realization doing its first aquatic test.

VI. EXPERIMENTAL PROCEDURE

As in part 1, the sensors were calibrated and connected to the SWIM stick aboard the autonomous pod. In addition to the on board SWIM stick, another prototype was developed, using a Teensy 3.6 as the micro-controller to measure conductivity, transmissivity, water reflectivity, etc. For this prototype, three 100-watts LEDs; red, green, and blue, were used for sufficient brightness underwater to make the light trail more discernible on the final photograph.

Fig. 5: Constructing the components of the autonomous watercraft

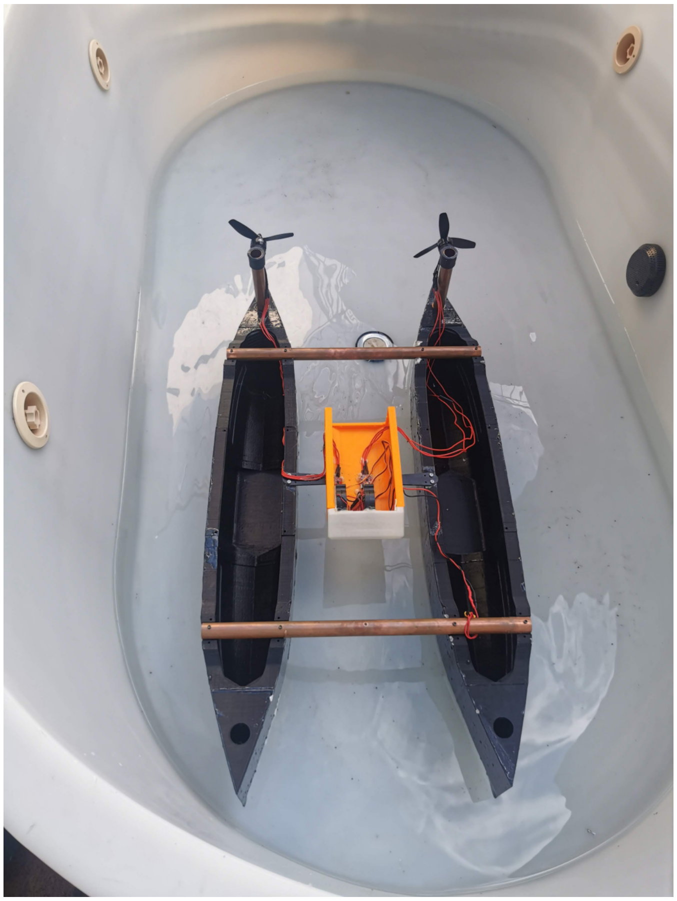


Fig. 6: Physical component of the autnomous watercraft made with CAD

Further, a data-logging system was used aboard the autonomous craft in conjunction with the overhead imaging drone to capture data and correlate with position/waypoints, etc., to build an environment map displayable in VR/AR/XR. As in pat 1, when light levels permitted (i.e. when it was dark enough) long-exposure photographs were taken and saved, to create additional data overlays.

The prototype sensor pod was towed by an autonomous watercraft across the test area. While conducting the experiment, a long exposure photograph is taken of the apparatus moving across the water - hence, a light trail indicating the correlation between the spatial coordinates and the water temperature is recorded on the photograph. At the same time, the overhead imaging drone was capturing the autonomous watercraft's path and surrounding data to overlay as environment heatmaps.

VII. TESTING

Here we focused on building on Part 1's exploratory mission by using the proposed system towed by an autonomous watercraft as shown in Fig. 7. The autonomous watercraft approach was proposed to mitigate the effect of the swimmer's stamina on the final image. Compared to a human swimmer, the autonomous watercraft possessed several advantages:

1) Smaller speed variations which shall show a more uniform brightness on each data point along the trail
2) Non-biological structure that allows the performance in water areas that are not suitable for swimmer, e.g. high E.coli water regions
3) With a proper control and geo-location system, a trace of the same path can be achieved across multiple trials which provides a more coherent data correlation
4) The autonomous nature of the watercraft grants it the ability to traverse deep into areas where would be considered unsafe for a swimmer to travel

However, this approach also suffers from several problems as well:

1) The autonomous watercraft relies heavily on batteries to maintain its functioning, which reduces the number of experiments that can be conducted on a single visit;
2) The sensitivity of the electronics requires a better sealing of the compartments to prevent damage to the electronic parts.

The problems imposed by this approach can be easily mitigated with more mature design and a better system, which made it the ideal future platform to use. However as a teaching and fundamental understanding tool, we propose that the autonomous watercraft can help visualize the sensing of water quality in a more scientifically reproducible process than that presented in Part 1.

VIII. RESULTS AND DISCUSSION

We created a VR/AR/XR system to help understand and teach principles of environmentalism with regards specifically to understanding of beach water, and the spatial variation of beach water characteristics. This is an important first step towards developing a system to understand, teach, and care for our beaches, and to create an outreach program to educate the public about the importance of beach water quality.

We first tested the image capturing capabilities of our imaging sensors to ensure accurate SWIM depiction as shown in Fig. 8.

Next we performed rasters and free-from patterns in the water with the autonomous watercraft. This data was captured via the environment depicted in Fig. 9.

By taking long-exposure photos, we gained images in Figure 10 as our initial test results, which show the way in which water can be sensed and understood in realtime. The light trails created by the autnomous water craft allow for real-time sensing of the aquatic environment and are fundamental in the teaching and understanding of interactive water quality measurements.

Fig. 7: Autonomous watercraft pulling the sensory and meta-sensory payload. An overhead drone tracks the autonomous watercraft's position within the body of water, based on the unique shape and color pattern of the watercraft.

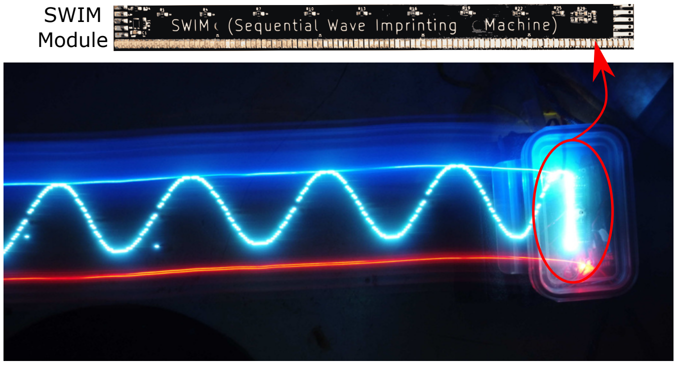


Fig. 8: Testing of the DJI Mavic Mini drone's capacity to capture a long-exposure time-integrated photograph of the sensor pod as it passes beneath, while the SWIM presents a test pattern (sine wave).

We also plotted the following graphs using the data we collected with the apparatus using the bird's eye view of the DJI Mavic Mini, plotting the heatmap with warmer colours indicating warmer areas along the beach - See Figure 7, which demonstrated as below in Figures 11, 12, 13 at Woodbine beach and 14 at Kelso reservoir:

IX. CONCLUSION

Concluding this 2 part paper, we developed an autonomous watercraft to help in teaching and understanding the measuring of water quality. The autonomous craft performed raster and free-form patterns while being tracked by an overhead drone. The drone contained an on-board SWIM device enabling real-

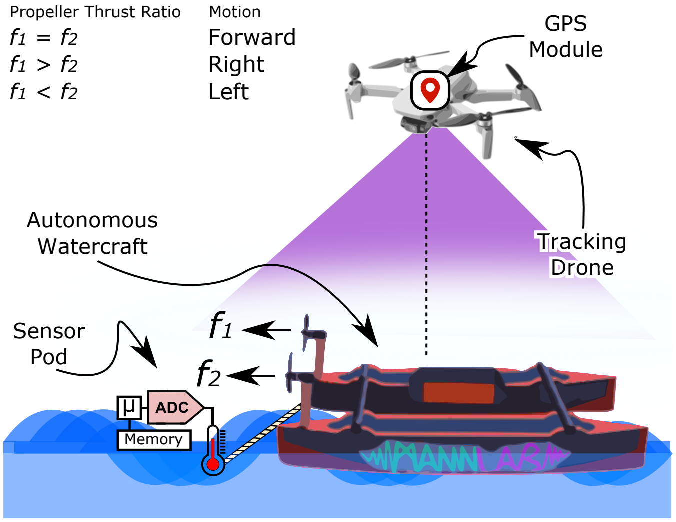


Fig. 9: The experimental setup for the autonomous spatial measurement of water temperature. Reproduced from [7]

time spatial encoding of water quality sensing via photographic sources. Additionally the interplay between the drones overhead imaging system and the autonomous watercraft's data collection allowed the construction of spatially accurate heat-maps over the testing environment.

X. FUTURE WORK

Apart from forming personal recommendations of best route through the water region, the future realtime autonomous water quality measurements will be combined with mesh networking, to supply timely updates of water quality, which shall benefit water conservatory with concurrent data.

XI. ACKNOWLEDGMENTS

We would like to thank Cayden Pierce for help in writing up some of the motivations, goals, objectives, etc., Liam Cassano for help with the boat design, and Mark Vytvytskyy and Hassaan Basit, Conservation Halton.

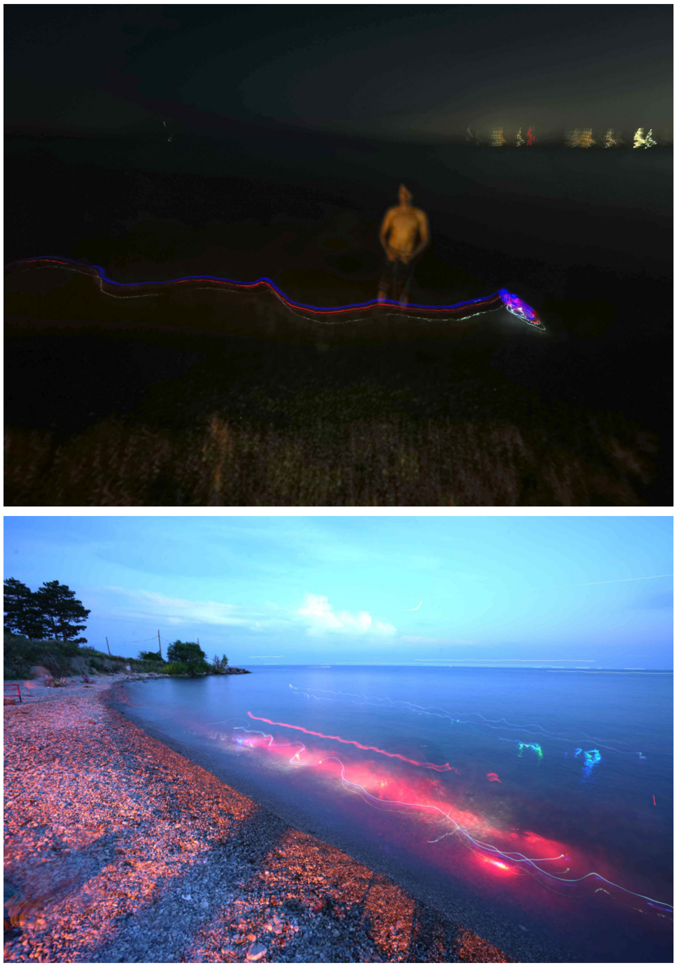


Fig. 10: Long-exposure photographs showing light trails from the sensor pod being towed through the water.

REFERENCES

[1] S. Mann and M. Hrelja, "Praxistemology: Early childhood education, engineering education in a university, and universal concepts for people of all ages and abilities," in *2013 IEEE International Symposium on Technology and Society (ISTAS): Social Implications of Wearable Computing and Augmediated Reality in Everyday Life*. IEEE, 2013, pp. 86–97.

[2] M. Gholizadeh, A. Melesse, and L. Reddi, "A comprehensive review on water quality parameters estimation using remote sensing techniques," *Sensors (Basel, Switzerland)*, vol. 16, no. 8, p. 1298, 2016.

[3] J. Kern and A. Schenk, "A multi-modal system for monitoring of water quality - setup and first results from passauna reservoir," 04 2019.

[4] C. G. Fichot, B. D. Downing, B. A. Bergamaschi, L. Windham-Myers, M. Marvin-DiPasquale, D. R. Thompson, and M. M. Gierach, "High-resolution remote sensing of water quality in the san francisco bay–delta estuary," *Environmental Science Technology*, vol. 50, no. 2, pp. 573–583, 2016;2015;.

[5] S. Mann, "Veillance and reciprocal transparency: Surveillance versus sousveillance, ar glass, lifeglogging, and wearable computing," in *ISTAS*. IEEE, 2013, pp. 1–12.

[6] M. Morrow, J. Iorio, G. Adamson, B. Biermann, K. Dow, T. Egawa, D. Gal, A. Greenberg, J. C. havens, S. R. Jordan, L. Joseph, C. Karasu, H. eun Kim, S. Kesselman, S. Mann, P. Mohan, L. Morgan, P. Noriega, S. Rainey, T. Richmond, S. Rizzo, F. Rossi, L. Seeto, A. Smithson, M. Stender, and M. Zuckerman, "Extended reality in A/IS," *The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems*, 2020.

[7] S. Mann, M. Mattson, S. Hulford, M. Fox, K. Mako, R. Janzen, M. Burhanpurkar, S. Browne, C. Travers, R. Thurmond, S. min Park, A. Roufas, C. Pierce, S. Khaki, D. Lam, F. Sadrzadeh-Afsharazar, K. Simmons, T. Yonezawa, and A. Manzoor, "Water-Human-Computer-Interface (WaterHCI): Crossing the borders of computation, clothes, skin, and surface," in *Proceedings of the 23rd annual Water-Human-Computer Interface Deconference*, Ontario Place TeachBeach, Toronto, Ontario, Canada, 12 2021, pp. 6–35. [Online]. Available: https://zenodo.org/record/5769045

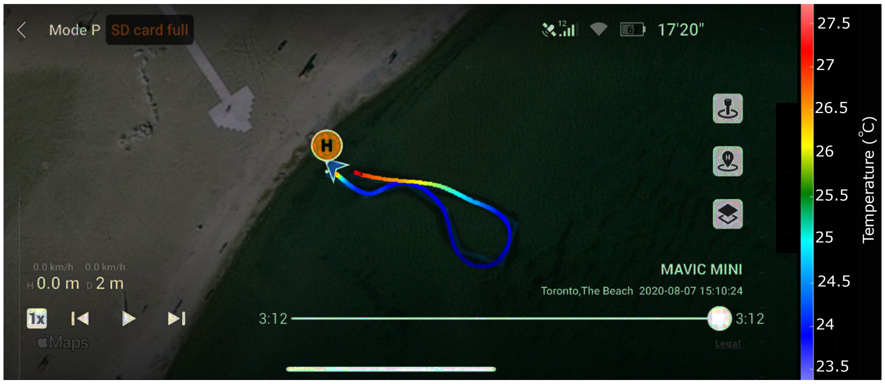


Fig. 11: Experimental Results 1, Spatially-resolved temperature heatmap at Woodbine beach

Fig. 12: Experimental Results 2, Spatially-resolved temperature heatmap at Woodbine beach

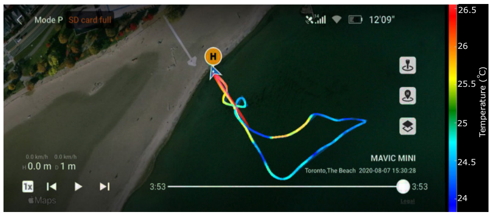


Fig. 13: Experimental Results 3, Spatially-resolved temperature heatmap at Woodbine beach

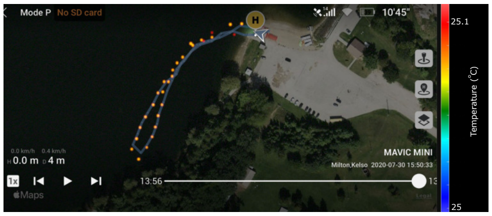


Fig. 14: Experimental Results 4, Spatially-resolved temperature heatmap at Kelso Reservoir