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Powertrain photography and visualization using SWIM (Sequential Wave Imprinting Machine) for veyance safety

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***Abstract*—We explore the use of the SWIM (Sequential Wave Imprinting Machine) to visualize and photograph electric motor voltages and currents plotted as a function of position in a way that also captures the effects of a vehicle, vessel, (con)veyance, or vironment's drivetrain, or the like, as well as other effects such as wheel, propeller, or paddle slippage. We explore SWIM as an eXtended Reality (XR) for safety. Whereas an oscilloscope can show these voltages and currents as functions of time, our use of SWIM shows them as functions of space, situated in visual reality, i.e. as an augmented reality (AR) or extended reality (XR) that can be photographed or viewed by the human eye without the wearing of any special eyeglass or headset. Whereas previous work on SWIM typically uses rotary SWIM to visualize or photograph rotary phenomena (e.g. the behaviour of an electric motor) and linear SWIM to visualize or photograph linear phenomena, in this paper we propose and demonstrate the use of linear SWIM to capture rotary phenomena, such as the combined effect of a rotary electric motor on vehicle/vessel/veyance/vironment propulsion.**

***Index Terms*—SWIM (Sequential Wave Imprinting Machine), electric machines, powertrain, drivetrain, electric vehicles, ebikes, vessels, veyances.**

I. BACKGROUND AND RELATED WORK

The SWIM (Sequential Wave Imprinting Machine) was invented in Canada in 1974 as a form of eXtended Reality [1], [2], [3], [4], [5] (XReality or XR, http://wearcam.org/xr.htm) for the realtime display or photography of electromagnetic waves (e.g. radio waves), sound waves, and the like [6], as well as for the realtime display or photography of the electrical signals associated with rotating magnetic fields in electric machines [7], [8], as well as for the realtime display or photography of sound waves and other propagatory waves in solid, liquid, gas, or other matter. SWIM has origins in marine radar and sonar (e.g. display or photography of sound waves underwater), and was also an early example in the new field of WaterHCI (Water-Human-Computer Interaction) [9], [10].

Photography enjoys a long-lived tradition as a form of evidence that appeals to juries, judges, and courtrooms, as well as to visual artists and educators, and often provides a more accessible and more convincing presentation of results than other forms of data or testimony [11], [12], [13].

SWIM is in some sense a form of virtual, augmented, or eXtended reality (XR) or eXtended Veyance/Vironment (XV) oscilloscope that is aligned with physical reality [1]. Typically the display shows as a function of space rather than time, as shown in Fig. 1, where we see a photograph of a sonar system (sound waves). Typically, when displaying or photographing sound waves, a microphone, loudspeaker, or hydrophone moves back-and-forth through air or water or other sound-conducing medium, together with a linear array of light sources (SWIM Wand). Typically the SWIM Wand consists of a hundred or more miniature LEDs (light emitting diodes) in which one LED is illuminated, and the position of the illuminated LED depends on voltage. It functions much like the trace of an oscilloscope, but moving out in the real world rather than contained within the box of a scientific instrument. In this way SWIM overlays waveforms in alignment with the world in which they are sensed. SWIM is an example of XR in the eXtendiVerse (XV) in contrast to the "Digital Reality[14]" of the metaverse [15], [16]. The metaverse is a universal and immersive virtual world, whereas the XV is a universal and immersive XR.

The example shown in Fig 1 is an example of *linear* SWIM, whereas other examples of SWIM also include rotary SWIM. Previous work in making the inner workings of electric machines visible includes "Moveillance"[7], [8] which reveals in real-time the inner workings of a motor, using rotary SWIM (one or more linear arrays of LEDs mounted radially outwards from the motor). See Fig. 2. In the top photograph a linear array of 100 green LEDs can be seen rotating around with the motor body, while the shaft is fixed. The photograph was taken with "slow sync" electronic flash to "freeze" the motion while allowing the exposure to display the waveform as well [17], [18], [19], [20]. The leftmost LED illuminates when 0 volts is present. An amplifier scales a sensed quantity (such as voltage or current) on an interval from zero volts to a reference voltage, and each LED illuminates next for every 1/100th of the reference voltage. The result is a polar oscilloscope of sorts that is perfectly aligned with the physical body of the motor. In the bottom row, a red, green, and blue LED strip can be seen displaying each of the three phases of the three phase motor (reverse-polarity on green), made to be interactive so that a user may stall or rotate the motor and immediately see the

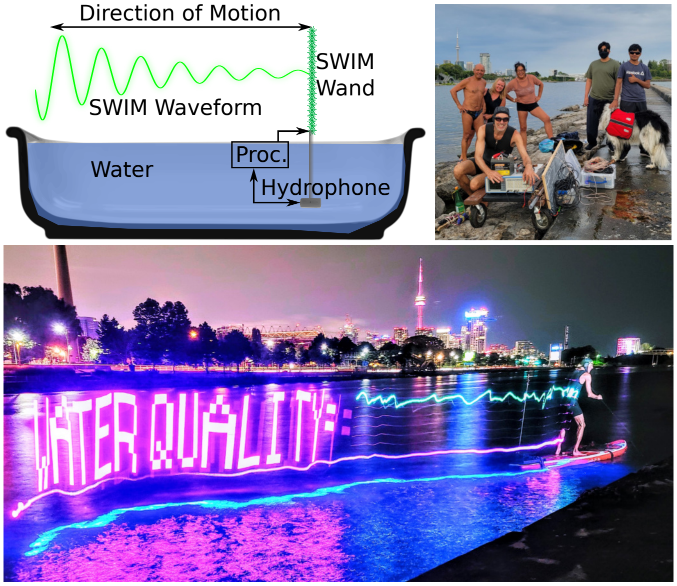

Fig. 1: Schematic diagram of the linear SWIM, an early form of WaterHCI (Water-Human-Computer Interaction) invented in 1974, together with more recent photographs showing its use upon a vessel (SUP = Stand-Up Paddleboard) for applications in water safety. Top right: photograph of the SUP-shore communications and realtime processor. Bottom: photograph of the time-varying waveform in green, with axis-labeling ("WATER QUALITY") in magenta, as light trails left by the paddleboard and paddler visible at the right side of the photo. By sensing water quality in real time, important aspects of aquatic safety can be sensed and communicated immediately.

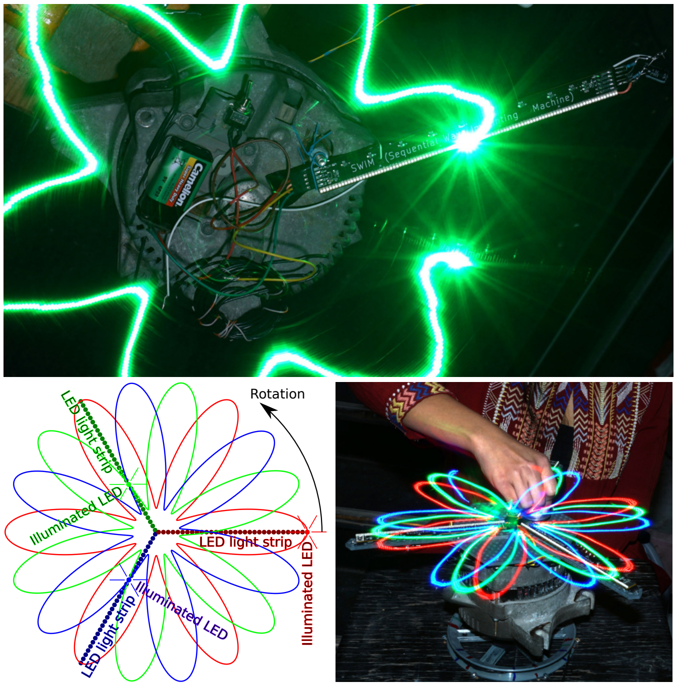

Fig. 2: Rotary SWIM allows users to safely see and interact with voltages or currents associated with rotating magnetic fields.

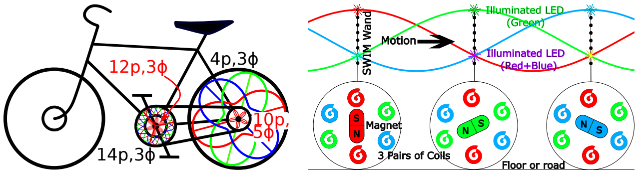

Fig. 3: Left: Motors and corresponding SWIMs can be installed on various rotating bike components. Right: Using a linear SWIM to capture the combined effect of motor and drivetrain.

effect of the motor's internal rotating magnetic field. Here the motors were fixtured to a workbench for teaching purposes.

II. SWIM FOR VEYANCE SAFETY

SWIM is now proposed to visualize and photograph the electric currents flowing in electric veyance (vehicle, vessel, or vironment) motors [21], [22]. To illustrate by way of example, an electric bicycle ("ebike") is selected in which an electric motor provides "pedal assist" (i.e. in a bicycle that uses an electric motor to ease the physical effort of a cyclist's pedaling) [23], [24], [25].

Motors can be installed in various places within a bicycle, e.g. before or after a crankcase transmission, or before or after a back wheel transmission [26]. Possible motor locations, pole counts, and phase configurations are shown in Fig 3 (left), similar to how the SWIM(s) is (are) installed in Fig 2.

However this situation fails to show the entire drivetrain effects as well as the effects of vehicle wheel slippage, or propulsion slippage.

III. LINEAR SWIM FOR OBSERVATION OF ROTARY PHENOMENA

Accordingly, the use of linear SWIM is proposed to capture the effects of rotary phenomena, as illusrated in Fig 3 (right). Here a linear SWIM using RGB (Red, Green, Blue) LEDs (Light Emitting Diodes) is electrically connected to a rotating electric machine. Three dots are sequenced, one in red, another in green, and another in blue, along the SWIM to trace out the 3 phases of the motor. A photograph of this setup is shown in Fig 4 wherein a hub motor is manually pushed across a floor. Three analog inputs on the microcontroller (ESP32 D) are connected to the 3 phases of the motor, resulting in motor voltage being displayed . The top row of Fig 4 shows 2 photographs of the SWIM swept through an arc while the wheel sits on the floor, thus confirming visually (photographically) 5 lobes over 180deg, i.e. 10 lobes, i.e. 10 pole-pairs, indicating that the motor is a 20-pole motor [27]. The wheel diameter is specified as 10 inches which we measured as 26cm indicating a circumference of approx. 10π inches ($\approx$ 82cm), so as to provide a spatial wavelength of approx. 82cm / 10 cycles = 82mm / cycle observed on the linear SWIM.

The SWIM has also been programmed to label the left-to-right axis to indicate the quantity being measured ("PHASE

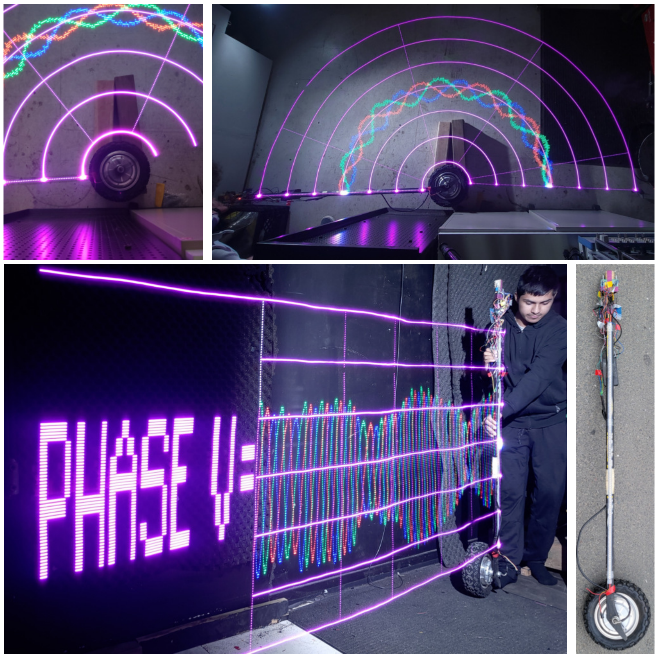

Fig. 4: Hub motor with wheel manually pushed across floor.

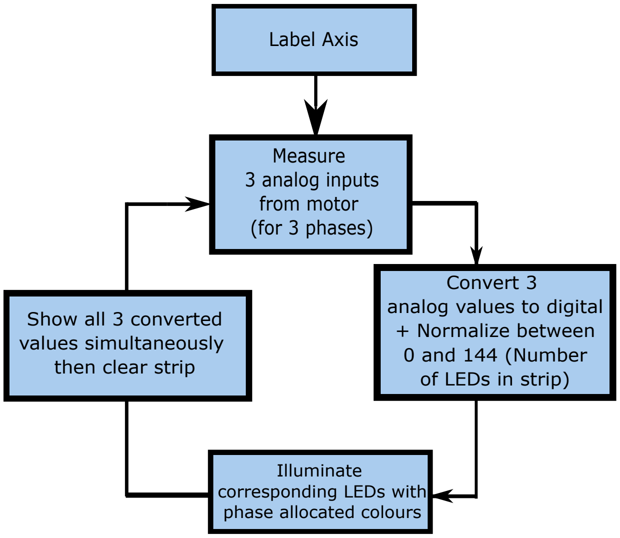

Fig. 5: Flowchart of SWIM process.

V=”) and to provide a graticule (reticle) using the purple/violet/magenta color (red + blue) [28]. The graticule is generated by maintaining a number of LEDs always on in the graticule color (e.g. here, the red and blue LEDs at the graticule points are kept on) to generate the graticule going across, and then also flashing all the LEDs in the entire strip briefly on to generate the graticule lines going up-and-down. The programming of the SWIM is illustrated in Fig 5.

The hardware configuration comprises a linear array of 144 RGB (Red Green Blue) LEDs (Light Emitting Diodes) connected to a microcontroller (ESP32 D) that performs the font character generation for axis-labeling, graticule generation, and scaling of the electrical signals for display [29]. Three differential amplifiers provide for connection to any 3-phase electric machine whether in star or delta configuration.

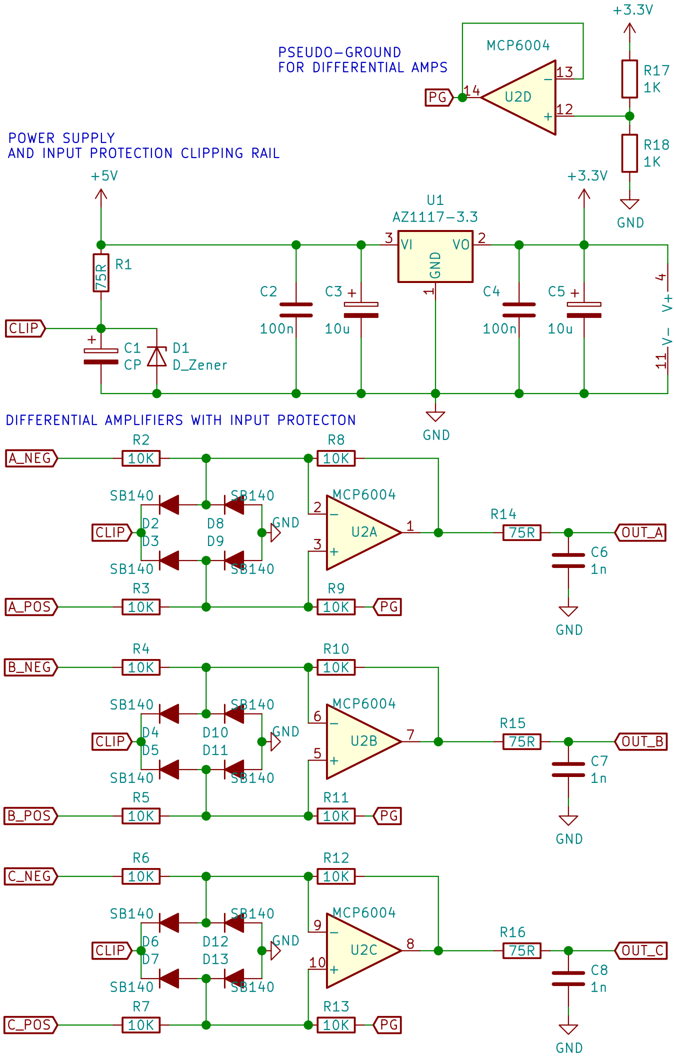

Fig. 6: Schematic diagram of voltage protection/isolation.

Voltage protection and isolation (diff. in) is provided for safe connection to higher voltage machines [30][31][32]. See Fig 6.

IV. PHOTOGRAPHY AND OBSERVATION OF POWERED MOTORS

A Kodiak Voltbike was outfitted with a SWIM connected to the 3 phase windings of its hub motor. The Bafang hub motor has a built-in gearbox with a 5:1 gear ratio, driving a 26x3 inch wheel [33]. The wheel’s outer diameter was measured at 27 and 3/8 inches (approx. 69.5 cm) and the motor has 10 lobes per turn times a gear ratio of 5, giving 50 lobes per turn, i.e. 50 cycles per circumference of 218.4cm which gives a spatial wavelength of approx. 43.7 mm per cycle (about 1.72 inches per cycle).

Fig 7 is a photograph of the SWIM wherein, as with Fig 4, three inputs on the Espressif Systems ESP32 microcontroller are connected directly to the 3 phases of the ebike motor, resulting in motor voltage once again being directly displayed, albeit displaying voltages being inputted to the motor rather

Fig. 7: Photograph of e-bike SWIMming motor voltages.

than being generated by it. We see that the waveform shows a pattern but since a typical motor controller controls current, not voltage, the pattern observed is quite rich in spurious high frequency harmonics.[34]

Fig 8. is a photograph of the bicycle + SWIM with current sensors inserted in series with each of the 3 phase windings. Isolated Hall effect current sensors were selected, Melexis Technologies part number M21KDC-ABR-020-RE [35][36] (Digikey part number 413-MLX91221KDC-ABR-020-RECT-ND) that provide transimpedance amplification of 0.1 Ω = 100mΩ. Currents of 0 to 20 Amperes are thus converted to voltages in the 0 to 2 volts range, suitable for displaying on the SWIM operating as a voltmeter, as previously done in [37].

V. SWIM WITH CURRENT SENSORS

In the photograph, the cyclist is initially coasting down a hill, proceeds to use the pedals to accelerate causing a significant increase in motor current as shown, followed by a cessation of pedalling resulting in a lower waveform amplitude once again.

Knowing the exact length of the bicycle and counting the number of cycles in this length, a spatial wavelength of 1.7 inches (4.32 cm) per cycle was determined, giving an experimental error of approximately 1.1 %. This small error could be explained by slip on the dirt-covered path.

VI. SAFETY FIRST!

SWIM has wide application in safety for all manner of con/decon/veyances (vehicles, vessels, and vironments). As a simple example, we were able to use SWIM to study e-bike drivetrains in detail, and, based on this SWIM-related research, invent a safer way to push an e-bike up a steep hill. Presently e-bikes have a walk or push function that engages at a fixed specific speed, but this can result in hazards on, for example, while pushing the bike up a steep hill at a pebble beach. The combination of poor traction and sunbathers and others slowly moving about creates a need to slow down and speedup as well as start/stop, and use of the throttle is difficult while pushing the bike. Thus we developed the concept of a pushbike handlebar with force sensors to proportion the throttle to force [38]. We also developed a beach wagon that operates on a similar principle with a rubber cord impregnated with conductive material as a pull mechanism to control the throttle based on position. We also developed a similar system for swimmers to be able to safely haul heavy equipment without much force required. Since the system uses a paddleboard to haul the equipment, it serves also the interest of safety by having a vessel follow the swimmer. The swimmer can use the vessel in case of emergency and also the vessel is highly visible to other vessels, thus reducing the chances a vessel would not see the swimmer in the water.

SWIM has wide applications areas for safety in vehicle design and usage, as well as design-for-safeaty and safe usage of other veyances such as vessels. In the world of WaterHCI, various taxonomies have been proposed. With a particular emphasis on safety, one such taxonomy is the PV (Pressure-Volume) Taxonomy or the Pressure-Flow Taxonomy (Fig 9). Safety issues exist when there are large quantities of water, or water at high pressures. The presence of water near electrical equipment often creates safety hazards. Another safety-centric taxonomy we proposed is the IV-Taxonomy in which the plane of voltage (across) and current (up) is used to classify devices and systems, e.g. batteries are often low voltage high current (upper left quadrant), EEG and ECG biosensors are low voltage low current (lower left quadrant), etc..

Our research is directed at vehicles, vessels, vironments, and veyances, and the like as cybernetic extensions of the human mind and body (i.e. as cyborg technologies) and thus we seek to use SWIM to better understand the world around us, and to broaden the concept of what is meant by “vehicle” to any kind of cyborg prosthesis of sorts, including clothing. Manfred Clynes, who coined the word “cyborg” said that his favorite example of a cyborg is a person riding a bicycle, and yet if we consider a vessel also as cyborg prosthesis, then cyborgs have existed long before the invention of the vehicle, or even the invention of the wheel, or of clothing. Even before homo-sapiens, cyborgs existed more than a million years ago with our ancestor hominids inventing, making, and using vessels [39]. In regards to vehicles there was also presented the idea of a MVV = Minimum Viable Vehicle (or Vessel), that asks the question: What is the smallest amount of vehicle or vessel that permits a person to be on a road or access a drive-through restaurant or be in a “no swimming” (vessels only) area?

WaterHCI has existed for 54 years (since 1968) and as an academic discipline for 24 years (since 1998) [9], in which Grand Challenges have been identified, particularly around safety. These ideas took shape in discussions over the past 25 years of WaterHCI, and, more recently, WaterHCI-2021 [9] and a subsequent workshop on WaterHCI [40]. The four Grand Challenges are:

1) **Water-Tech**: Waterproofing of electrical and computational equipment, sensors, etc., and inventing, designing, and building sensors that work well in wet environments, e.g. lidar that can “see” through steam, fog, and underwater.
2) **UX/UI**: Studying, designing, building, and testing user-experiences and user-interface designs that work well in an aquatic environment.
3) **Water law, ethics, and justice**: How do we ensure safety in water environments, safety of vessels, etc., and how do we ensure justice and human rights, such as the

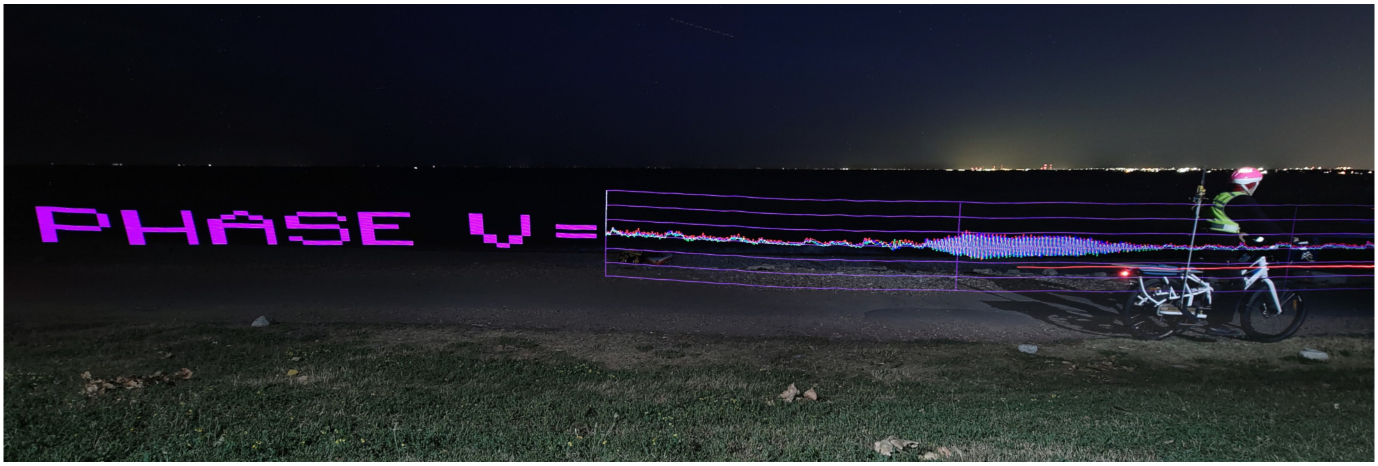

Fig. 8: Photograph of e-bike SWIMming motor current (voltage at output of transimpedance amplifier).

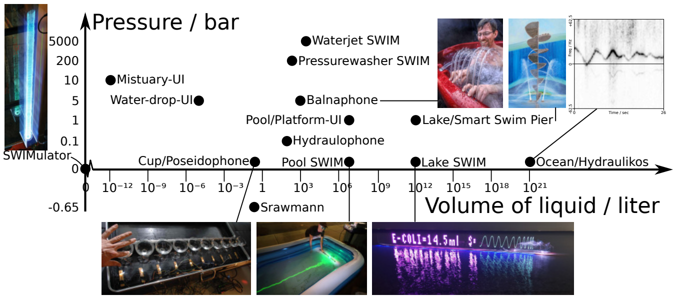

Fig. 9: The safety-centric WaterHCI PV (Pressure-Volume) Taxonomy from WaterHCI-2017 and WaterHCI-2021 [9].

right to swim, to drink, and to fish the waters (SDF), and the right to access beaches with or without a vessel.

4) **WHC-Core**: WaterHCI creates new Grand Challenges and opportunities that bring together all of the above categories. Consider for example the "washbus" (WaterHCI DECONference 2002) which is a vehicle designed for safety in the event of a mass decontamination scenario. It can decontaminate passengers while they are being transported. The SWIM requirements of the vehicle are embodied in both the drivetrain (powertrenograpy) and at the same time SWIM displays water flow, head, and distribution throughout the mobile shower system.

Whereas all four categories of Grand Challenges encompass all 3 elements (Water, Human, and Computer), each category concentrates primarily on the areas indicated in the Venn diagram of Figure 10.

VII. BIG SAFETY AND LITTLE SAFETY

SWIM is an example of XR (eXtended Reality) in the eXtendiVerse (XV), and SWIM is an embiment of Humanistic Intelligence, often abbreviated HI, HIntelligence, HIntel, or HInt. HI is an alternative to the general ideas of HCI (Human-Computer Interaction) that regard the human and computer as separate entities, or as a "team" working together. Instead we regard the computer as a true extension of the human mind and body in the cyborg sense, e.g. technologies like SWIM take on a kind of prosthetic territory through long-term adaptation to their use.

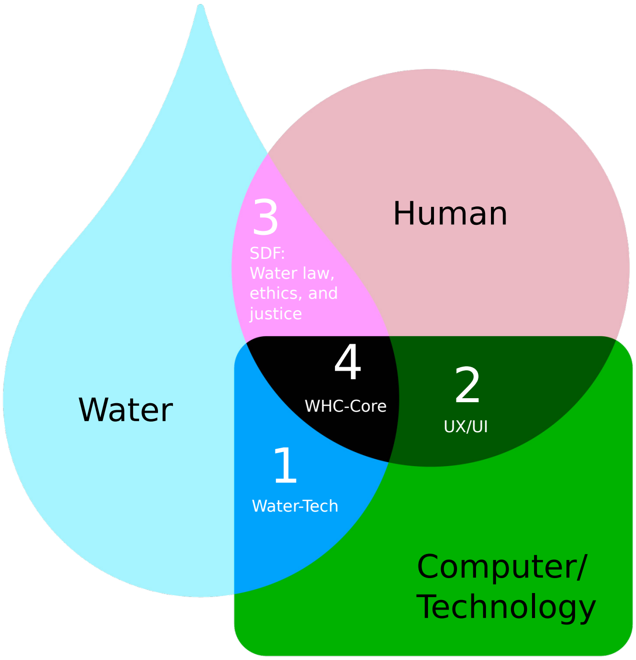

Fig. 10: Venn diagram showing the four categories of Grand Challenges in WaterHCI.

In regards to safety, we may define XR, XV, and HI as tools with which to see and understand the world of veyances to make them safer, but we can also ask questions about the safety of XR, XV, and HI itself. In order to better-understand the safety landscape, it is helpful to define different categories of danger, ranging from "little danger" to "big danger" akin to the dichotomy between "little data" and "big data"[41]. Danger, and its inverse, safety, can be thought of in terms of their scale (size), both physically, sociopolitically, and virtually (big data versus little data), through the scalespace concept[41] outlined in Fig 11.

This insight began as an exploration of a taxonomy of technologies in a two-dimensional plane, where the across axis ("x-axis") is the degree to which we think of the technologies as being associated with our bodies, and the up-axis ("y-axis") is the sense of control, self-determination, and freewill ("existentiality"). This concept was first published by Mann in 2001 [42], and later, the same two-dimensional plane was proposed, without attribution, as a taxonomy of human-computer integration [43]. The indications of [43] are annotated in red upon the original Mann 2001 figure of 20 years earlier. See Fig 11(a). In more recent thinking about the BOC-plane, it appears to make conceptual sense to reverse the direction of both axes, giving rise to a Physical scale axis (1/Body) and a sociopolitical scale axis (1/Control), and to also add a third axis, Informatic scale (1/Ownership). Given the recent interest in these issues, we feel compelled to emphasize their importance to safety. In particular, the proliferation of "big data" and "big watching" (surveillance) represent the extremities of these axes, labeled β and γ respectively. More generally, "big data", "big watching" and "big environment" (the extremities of all three axes) represent a possible danger when not balanced by their counterparts, "little data" (distributed sensing, distributed ownership, etc.), "little watching" (sousveillance[44], [45], [46], [47]), and the counterpart to the environment, namely the invironment.

SWIM has been explored extensively in this context, e.g. as metaveillance and veillametrics for sensing surveillance and sousveillance systems[48], [49], [50]. See for example SWIM used in a metaveillance-safety context in Fig **??**. Police radar is commonly used for surveillance to ensure safety, and this protects us from the dangers of individuals operating their vehicles unsafely. But what protection do we have from the dangers of excessive police powers, excessive surveillance, etc., which could create massively existential dangers to society as we know it? Thus a fundamental question regarding safety is the tradeoff between surveillance and sousveillance, and likewise the role that metaveillance can play in not just vehicle safety [51] but also in the safety of society as a whole (e.g. open-sensing, free source, open governance, transparency, etc.). Interestingly, the discovery of SWIM was made while moving an oscilloscope with a transparent cathode ray tube in front of a police radar, the transparent CRT being an example of transparent technology.

VIII. CONCLUSION

A system was successfully created for visualization and photography of the effects of electrical voltages or currents in rotating electric machines, in relation to linear movement. The system consists of a SWIM (Sequential Wave Imprinting Machine) affixed to a moving vehicle such as an electric bicycle, to be carried along the path of the vehicle, while displaying the electrical quantities of the rotating machinery. Additionally, SWIM was contextualized within the broader intellectual landscape of veyance (vehicle, vessel, vironment, etc.) safety.

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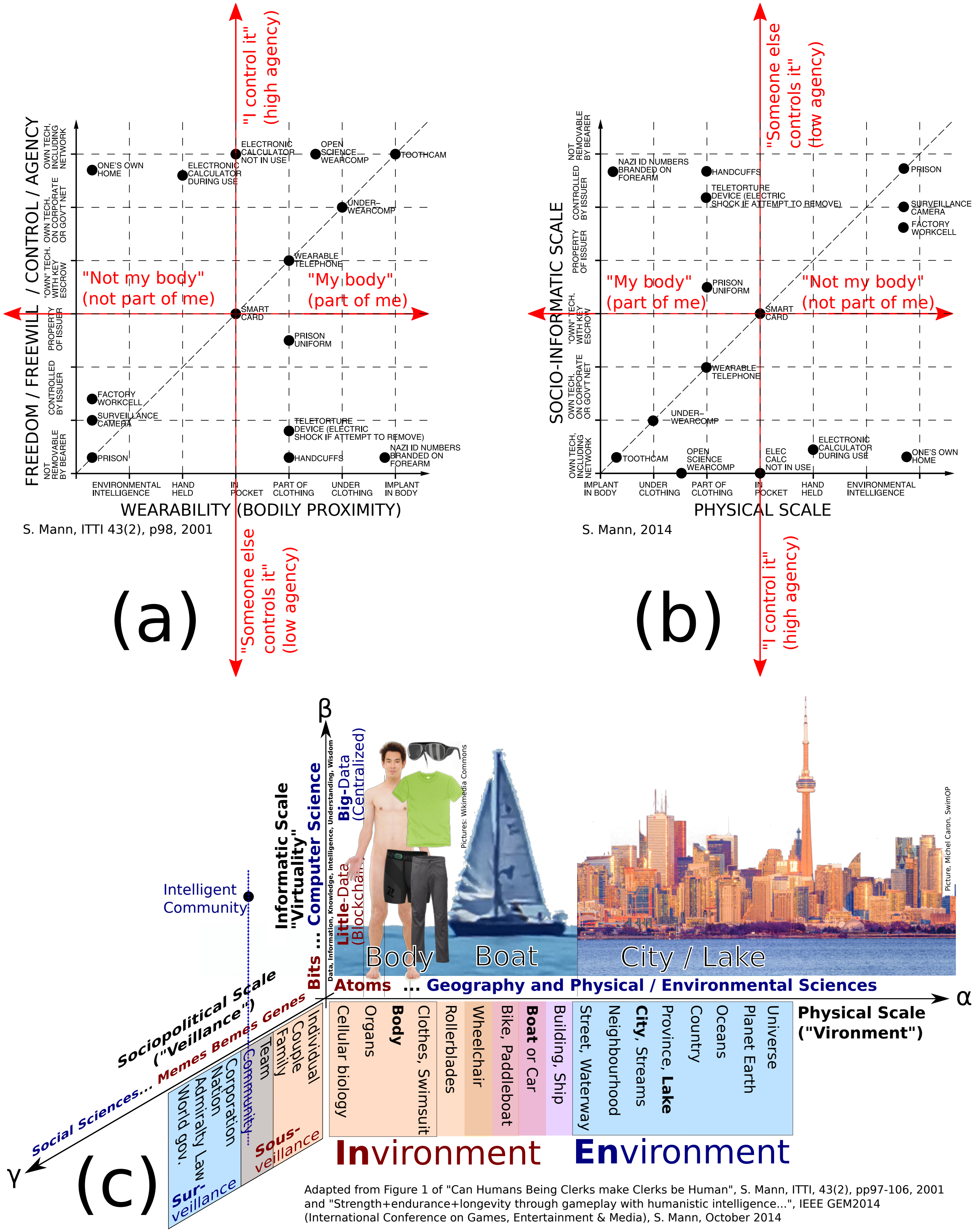

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Fig. 11: The Mann BOC-plane (Body, Ownership, and Control plane), 1991 to 2014 (a) The Body and Control plane[42] (b) Reciprocal Body and Control plane (reversal of the two axes as physical scale and socio-informatic scale); (c) The reciprocal Body, Ownership, and Control (BOC) volume[41].

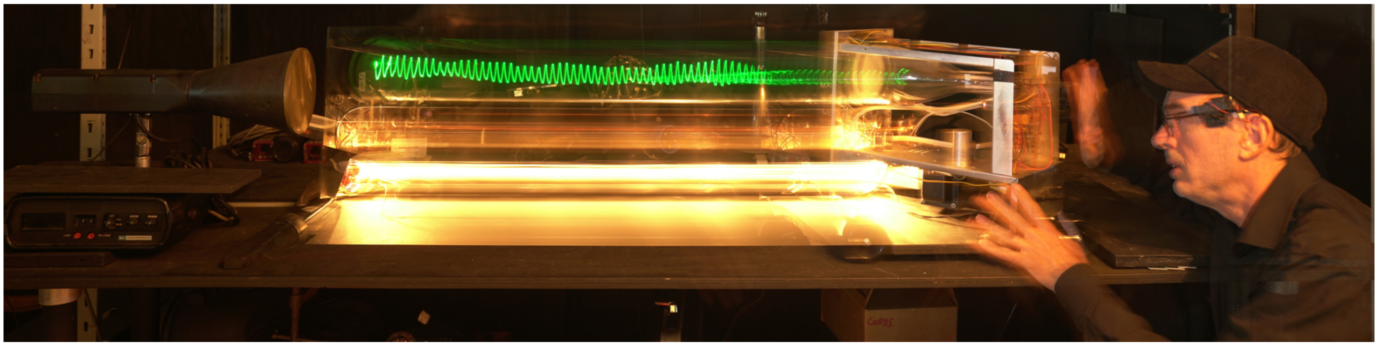

Fig. 12: Metavision / Metaveillance: Photograph of transparent cathode-ray tube moving in front of a police radar, while connected to the baseband Doppler signal.

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