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Keynote – Eye Itself as a Camera: Sensors, Integrity, and Trust

Steve Mann, Diego Defaz, Cayden Pierce, Derek Lam, Jeremy Stairs, Jesse Hernandez, Qiushi Li, Yi Xin Xiang, Georges Kanaan, Hongyu Chen, Graeme Aylward, Megan Jorritsma, Christina Mann
MannLab Canada, 330 Dundas Street West, Toronto, Ontario, Canada, M5T 1G5

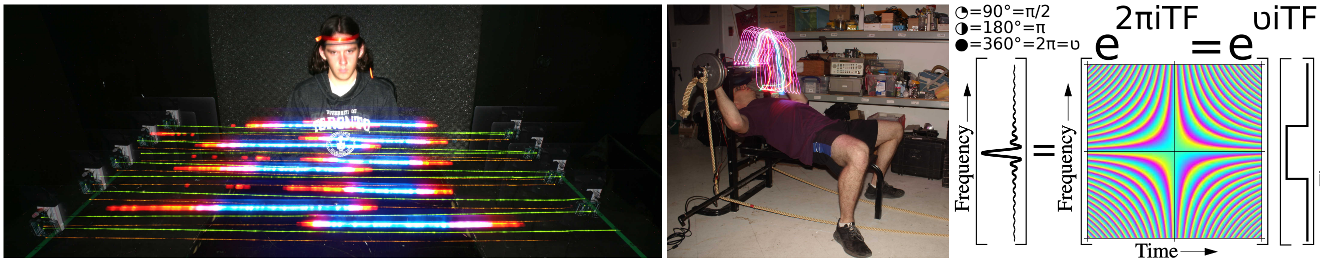

Figure 1: Integrity-of-completeness: (Left) Capturing brainwaves causes the human eye itself to function as a photographic camera (blue=maximum vision; note hysteresis). Prohibiting photography will become totally absurd! Surveillance is a half-truth without sousveillance. (Center) Kinematics (distance and its derivatives: speed, acceleration, jerk, jounce, ...) is a half-truth without also including integral kinematics, i.e. time integrals of distance. (Right) Pi is a half-teth (π=180°), whereas the Phoenician/Hebrew/Arabic/Oscan letter ʋ, teth, means "wheel", "bowl", "circle", "sun" or "disk" and defines the whole 360°.

ABSTRACT

Ayinography is the use of the eye itself as a camera. By recording brainwaves, we read the "mind's eye". Wearable ayinographic technology represents a new opportunity to solve an old problem: the lack of integrity inherent in the world around us. We live in a world of half-truths where incomplete evidence is collected about almost every facet of our lives. Wearable computing can and should provide the answer that allows us to capture and tell our own story, in a way that builds trust and integrity in service of truth, and ultimately, service of humanity through extended-reality intelligence (Human-in-the-loop AI). More generally we advocate whole truth through a full panoramic 360° wearable vision system (Teth Vision™), and a complete understanding of fundamental physics through *Integral Kinematics*.

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1 SENSORS AND INTEGRITY

Surveillance, as a professional practice, often involves secrecy: governments and corporations often wish to hide the function and purpose of their cameras. Cameras are often concealed behind darkly smoked acrylic domes that also contain metal shrouds to conceal the direction in which they are pointed, giving them a full 360° concealed gaze.

Wearable computing is a unique form of sensing in which, typically, the sensors are under the purview of an individual wearer. But many business and government establishments forbid recording by individuals. This is problematic for individuals who use wearable computers to help them see (e.g. wearable cameras) or remember (e.g. visual memory prosthetic [Mann 1996]). We're developing technologies that make the human eye itself function as a camera. This raises an interesting philosophical question: if the eye itself is a camera, and cameras are forbidden, we absurdify the hypocrisy of "no photography" in our highly surveilled society.

Surveillance without sousveillance is a half-truth in which one party captures and records evidence while (1) destroying evidence captured by other parties, or (2) equivalently forbidding other parties from capturing their evidence in the first place (Fig 2).

"Integrity" is a Latin word from the same root word as the word "Integer" or "Integral", meaning "intact", "soundness", "wholeness", and "completeness".

In order to exhibit integrity, an environment of completeness must be possible. A system where institutions can freely engage in surveillance whilst forbidding sousveillance is not a complete system, and is thus a system of half-truth – devoid of integrity. To remedy this issue, individuals' freedom to exercise sousveillance must be guaranteed as a basic human right, i.e. ownership of one's own senses, including one's own EVG (Electro-Visuo-Gram). The EVG (phase-coherent detection of EEG from vision) can be used to construct an image – the ayinograph.

2 EYE IS A CAMERA

Veillance gives a complete picture when we have both surveillance and sousveillance. The ultimate sousveillance is the point-of-eye (PoE) recording we're developing (Fig. 3). Since the eye can function as a camera, we track the eye's position while using a lock-in amplifier referenced to room-light flicker in order to measure how much a person can see (i.e. pixel value) for each direction of gaze.

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Figure 2: Surveillance is the veillance associated with the authority to prohibit other veillances, i.e. surveillance is the veillance of hypocrisy. The opposite of hypocrisy is integrity. Our wearable computer photographed Chinese text to translate it into English, yet it would appear that translation devices (as well as devices to make signs audible to the blind) are forbidden. "您已进入图像采集区域" = "You are under surveillance"; "禁止拍摄"= "Cameras prohibited." We also argue that the human eye can function as a camera, and that being able to remember what we see is a fundamental right AND responsibility (e.g. to testify in court about what was seen).

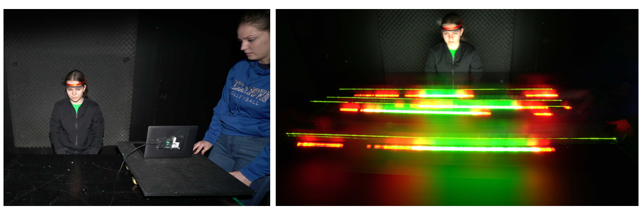

Figure 3: Co-author Christina is the subject of this "Mind's Eye" experiment operated by co-author Megan who moves a roll-cart back-and-forth. On the cart is a Macbook® displaying a subject-facing flashing checkerboard pattern. A lock-in amplifier referenced to the pattern is fed by an InteraXon™ Muse with OpenBCI occipital electrode. The amplifier drives a multicolored LED, allowing us to photograph the eye's capacity to see. Green indicates maximum veillance flux. Exposure time 8 minutes at f/22, ISO 100.

3 INTEGRAL KINESIOLOGY

Another example is in kinematics. The field of kinematics typically considers distance or displacement, x, and its time derivatives, $(d/dt)^n x$, $n > 0$. Integral kinematics includes integrals, i.e. n can be positive or negative (for $n = -1$, we have absement, $n = -2$, absity, and so on). There is logic in using absement (time integral of distance or displacement) and the time integral of momentum (which we proffer to name "momentement") as state variables.

Integral Kinesiology is a program of physical fitness based on principles of absement and momentement, in which we also propose complex-valued resistance training, as shown in Fig 1 (center). Here we have a bench press with mass (weights), springs, and friction (connected by cables, ropes, and cords). In our opinion only the friction (e.g. fluid damping) component should be called "resistance training" as the mass and spring should be considered "reactance training". Together we have a generalized complex-valued resistance training modeled as an electric circuit, together with tilt and position sensors and wearable sensors that provide real time feedback on how to do the bench press with proper form.

Our fitness training system accounts for 3 kinds of complex-valued resistance: (1) movement against a mass' gravitational attraction to the earth ("capacitance training"); (2) movement against a spring ("inductance training"), and (3) movement against a damping device ("resistance training"). This triad of impedances creates a more diverse workout.

4 PI IS A HALF-TETH (π = Ʊ/2)

Human vision has a roughly 180° field-of-view. Pi is a mathematical constant equal to the circumference of any circle divided by its diameter. Its symbol, π, appears in many mathematical formulae. There is even a day, March 14^{th} (3-14) called "Pi Day", founded at the Exploratorium in 1988. Since π=180°, it is really a symbol that represents half a circle. So we propose the use of the semicircle symbol "◖", instead of the symbol π. We also propose the full circle symbol ⊗ or ⊙ to denote 2π. Thus we write: ⊙=360°.

The Greek letter theta, θ, originates from the letter teth. Teth is a letter found in the Phoenician, Paleo-Hebrew, Arabic, Oscan, Western Greek, Etruscan (ancient Italy), Gothic, and old English[1] alphabets, and also as the "Sun cross" solar symbol[2]. The letter teth is written as Ʊ. It is also written as ⊗, ʘ, ⊗, or þ, and means "sun", "wheel", "cauldron", "pot", "pan", pie plate, or circle (complete circle), and in some fonts actually looks like a wheel with four spokes or a circle with all four quadrants present. Thus we propose using teth as a quantity equal to 360°. We propose Jun28 (06.28) as Teth Day (www.tethday.com), and Jun21-28 as Teth Week to celebrate wearable full 360° panoramic vision. Join us today (Jun21=date of publication) and every year thereafter, to celebrate Teth Week.

5 BIOGRAPHY

This paper is the result of work by many people, so here's our organization's biography: MannLab Canada, at 330 Dundas Street West, in Toronto, is the birthplace of many successful companies such as InteraXon, makers of the Muse (wearcam.org/interaxon.htm). Wearable computing also originated in the Toronto area in the 1960s and 1970s, along with many other inventions like HDR (High Dynamic Range) imaging (http://wearcam.org/hdr.htm).

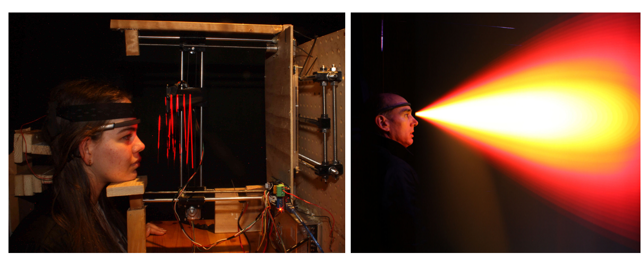

Figure 4: Left: Ayinograph of MannLab member Christina, captured with mechanical prototype. Head is stablized by wooden blocks behind it, and under chin, while stepper motors move a brain-modulated light source through space. Eventually the apparatus will be miniaturized into a wearable device. Right: Interpolated ayinograph™ of MannLab member Steve. Sparsely sampled SSVEP data is interpolated to make the high-resolution ayinograph.

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[1] As the letter "hwair", and later as the letter "thorn"

[2] Compare with the Chinese character "日" which means "sun", or "回", meaning "round", or "口", meaning "mouth".

Making Sensors Tangible with Long-exposure Photography

Steve Mann
MannLab Canada

Diego Defaz
MannLab Canada

John Xu
MannLab Canada

Daryl Chua
MannLab Canada

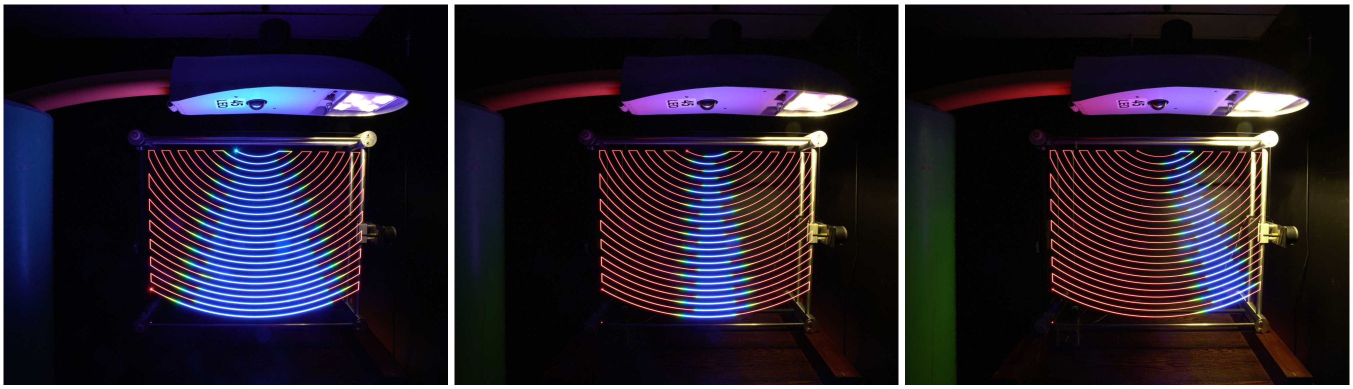

Figure 1: Metaveillography of smart street light with built in camera, wide, then zoomed in, then panned to the right.

ABSTRACT

We provide a simple way to make sensors (including wearable sensors) tangible. The result is a photographic depiction of sensing that is a form of photographic art, as well as scientific photography, allowing humans to easily see and understand sensors. Since photography is a preferable form of evidence, making sensors tangible may also have forensic value, e.g. allowing a judge or jury to be presented with photographic evidence of the efficacy or defects in sensors. We use robotics, digital video feedback, wireless communications, and long-exposure photography to see and understand smart city sensors and wearable camera systems in a new light.

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1 INTRODUCTION

1.1 Tangible computing

Hiroshe Ishii introduced the notion of tangible computing[15–18]. Kawsar et al. introduced the idea of sentient artifacts [21], bringing tangible computing to everyday objects [10]. In this way, the type of computing found in many everyday Internet of Things (IoT) [8, 23, 24], also falls under the umbrella of tangible computing, so that many of our everyday devices can become easier to understand.

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1.2 Tangible sensing

Our aim is to make sensing tangible, and thus to make the sensory capacity of wearable computing and IoT easier to understand and comprehend. To do this, we use robotics together with digital video or audio feedback and long-exposure photography to sequentially imprint (i.e. by robotic "light painting"), the spatially varying sensory capacity of a sensor. Photographs are inherently tangible. Photographs are often regarded as evidence that can be used by a judge or a jury, and, rightly or wrongly (even in the age of image manipulation with tools like Photoshop [41]), photographs are still seen as a form of truth or veracity. Thus we can use photographs to help make sensors and sensing more tangible, and more auditable, by not only large entities like governments or standards bodies, but also by end users.

1.3 Surveillance

Surveillance is a well-established field of research. The word "surveillance" is a French word, about 200 years old, and is formed from the prefix "sur" which means "over" or "above" (as for example in the words "surcharage" or "surtax"), and "veillance" which means "watching" [2, 26, 27, 42, 43, 49, 49]. Surveillance cameras have been in use for approximately 70 years [46].

1.4 Sousveillance and Dataveillance

Widespread connectivity among systems, together with computation and "Big Data" makes possible new veillances such as dataveillance [7, 40].

Figure 2: Surveillance cameras are typically affixed to property (real-estate) such as buildings or land (e.g. on lamp posts). Together with A.I. (Artificial Intelligence) and Big Data, such cameras also facilitate video analytics, such as automatic shoplifting detection, occupancy detection which is also used to automate lighting and other utilities. More recently, miniaturization of the technology has facilitated sousveillance, i.e. cameras affixed to individual persons, resulting in a new human-centric first-person viewpoint, along with wearable computing, giving rise to H.I. (Human-in-the-loop Intelligence). Figure from Wikimedia Commons.

Additionally, as the technologies of cameras and associated storage, processing, transmission, and image-based computation becomes miniaturized, it is now possible and practical (both technologically and sociologically) for individual persons to carry such technologies with them [22]. This gives rise to sousveillance [5, 6, 11, 13, 37, 39] and "Little Data" (distributed data) such as blockchain [25], in addition to surveillance and "Big Data" (centralized data).

It has been shown that, in a world dominated by smart cities, smart buildings, and smart things, there is a need to also put technology on people, i.e. wearable computing, or "smart people" [3].

For a comparison between the property-centric view of surveillance versus the human-centric view of sousveillance, see Fig. 2.

1.5 Metaveillance: Sensing sensors and sensing their capacity to sense

The Greek word "meta" means "beyond", e.g. a meta-conversation is a conversation about conversations. Metadata is data about data. Likewise metaveillance is the veillance of veillance (sensing sensors and sensing their capacity to sense).

One contribution to the field of wearable computing was the SWIM (Sequential Wave Imprinting Machine) from the 1970s[1, 29, 34]. SWIM was a system consisting of a wearable lock-in amplifier, wearable computer, and array of light sources creating an augmented reality or extended reality [38] overlay. This made visible the otherwise invisible meta-information of surveillance devices, as shown in Fig. 3. Metaveillance was created as both visual art [1, 29, 33] and scientific exploration [34]. More recently it was further developed by Janzen, Mann, and others [19, 35] as a form of scientific analysis.

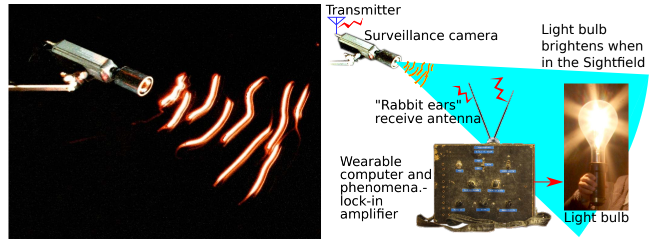

Figure 3: Mann's metaveillance apparatus from the mid 1970s [1, 29, 34] used one or more light bulbs fed from a wearable computer and lock-in amplifier designed to lock in on television signals from surveillance cameras. The light bulb transitions from a dim red glow to a brilliant white whenever it enters the camera's field-of-view, and then the bulb brightness drops off again when it exits the camera's field of view. Waving it back and forth in a dark room reveals to the human eye, as well as to photographic film (picture at left) the camera's capacity to "see". (Wikimedia Commons.)

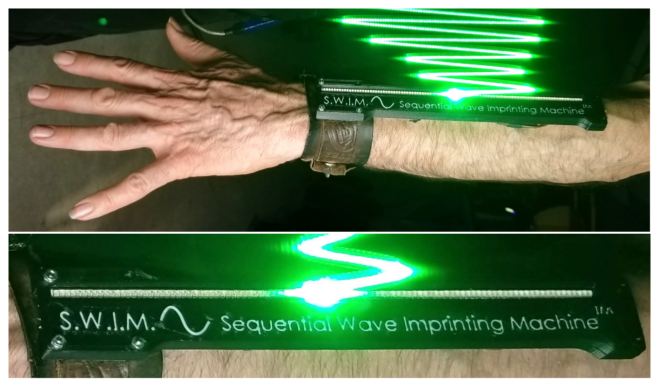

Figure 4: Wearable Sequential Wave Imprinting Machine™

2 STRUCTURED METAVEILLANCE

There are a growing number of sensors surrounding us in our everyday life, and we unknowingly pass by many such sensors that "see" or record us much of the time. Using wearable computing systems, we can "see" the capacity to see of those sensors as an augmented reality overlay imprinted on the real world. In order to do this we create computational "light-paintings" as scientific visualizations, where the degree of visibility of each sampled point in space of a sensor is itself made visible: "Metaveillance", i.e. sensing sensors and sensing their capacity to sense. In this paper, we demonstrate an approach to metaveillance by capturing it in a precise pattern of concentric arcs using a robotic mechanism driven by G-code. We show examples with both surveillance cameras and wearable camera systems. It is our hope that our approach will be useful to scientists and artists (and possibly judges and jury members) studying both surveillance and sousveillance devices such as those used in association with wearable computers.

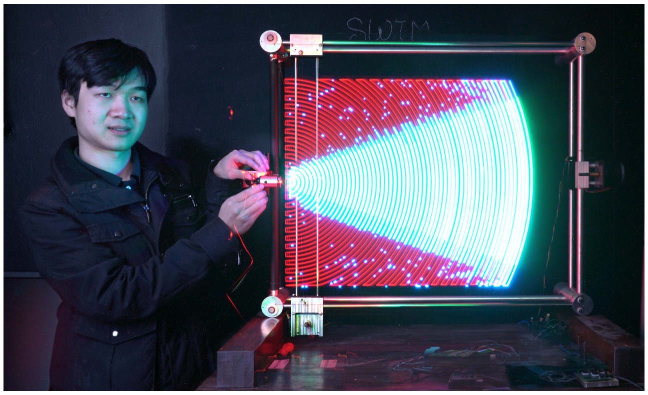

Figure 5: Metaveillography: Papalook PA150 USB web camera HD 720P. Red arcs show the full "canvas" traced by the G-code. Blue arcs show regions of medium sensitivity and green arcs show regions of high sensitivity.

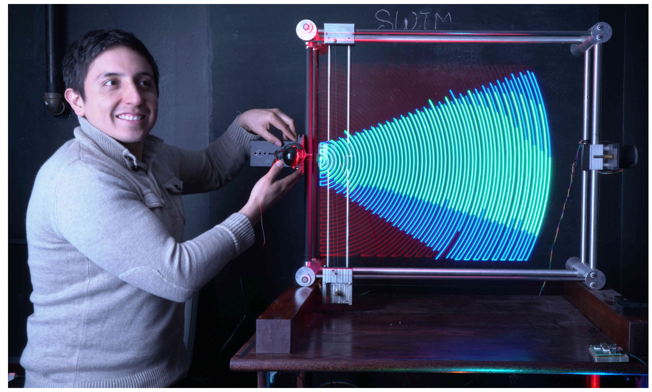

Figure 6: Metaveillography: Gear Head USB 2.0 1.3 MP Webcam for PC (WC750RED-CP10). Focus setup at minimum focal length, as expected the picture displays only a limited range of trust region (green). A small defect in the camera is visible near the bottom part of its field of view.

2.1 Approach

We propose a technique to evaluate sensors such as video cameras and ultrasound sensors. A feedback system with an amplifier, such as a lock-in amplifier, is used to drive an LED light source that is moved throughout the field of view of a camera or other sensor. In order to produce precise travel paths we use a RAMPS 1.4 shield for Arduino Mega to control stepper motors in the same way most actual self assembled 3D printers work. The result is graphical evidence of the effective range of vision of cameras, as shown, for example, in Fig. 5 and 6.

The principle of metaveillance was introduced by Mann in the 1970s [1, 29, 32, 34] which is the sensing of sensors (such as microphones and cameras) and their capacity to sense. For example, in order to visualise the field of view of a camera, one can shine a light at it. By receiving and amplifying signals from a camera and feeding these signals to a light source, a positive feedback loop results so that the light source glows brighter in the camera's field of vision. Furthermore, a long exposure photograph is taken while swinging the light source back-and-forth in front of the camera. This paper focuses on cameras, due to the increase demand for these devices as part of wearables, industrial systems, surveillance [14, 27] and sousveillance [4, 9, 12, 20, 28, 30, 36, 39, 44, 45, 47, 48]. Metaveillance also works within the framework of Extended Reality introduced by Mann and Wyckoff [38], and can be captured by way of an Extended Response ("XR") camera.

3 METHODOLOGY

The system for scanning the metaveillance of a camera consists of three parts: a mechanical robotic mechanism driven by G-code, an LED display stationed on a carriage that is moved by the mechanism, and the target camera connected to a Raspberry Pi 3.

Two or three stepper motors are controlled using a G-code interpreter to trace out a precise pattern of concentric circles, which serves as the "canvas" to display the metaveillography of light. The stepper motors move the carriage upon which the LEDs are mounted.

In the initial setup the LEDs were driven by an ESP-32 SoC with integrated Wi-Fi powered by a 9 volt supply. A custom board was created to attach to the ESP-32 pinout housing two front-facing LEDs (green and blue) and a side-facing LED (red). We wrote computer code for the ESP-32 to connect to the Raspberry Pi over WiFi and await messages. Transitioning from no signal to weak signal fades the blue LED on or off. Transitioning from weak signal to strong signal fades the green LED on or off. The red LED is always on to act as a primer for the camera and to show the full "canvas" traced by the G-code. The ESP-32 is mounted to this carriage.

The software on the Raspberry Pi 3 establishes a WiFi connection to the ESP-32. Using the OpenCV library, we detect and continuously track the presence of a bright LED and determine an amount of incoming light proportional to the maximum incoming intensity registered from the camera. To simplify the analysis, gray scale is used to extract the brightness information of the red LED. The internal logic implements a finite state machine that transitions between three states: No signal, weak signal, and strong signal. A transition between states will send a corresponding message over a TCP connection to the wireless transceiver on the carriage. Transitioning from no signal to weak signal turns the blue LED on or off. Transitioning from weak signal to strong signal turns the green LED on or off (and keeping the blue LED on). The red LED is always on for two reasons: firstly, to initiate the video feedback, and secondly, to show the full "canvas" traced by the G-code, so that we have photographic evidence that shows all the regions in which the camera was tested.

After our initial setup results, we decided to use an analog approach similar to Mann's original design [1, 29, 34] (Fig 3). Therefore, we use just one RGB LED to start the feedback and also change the color proportionally to the brightness detected. The brightness calculated in the Raspberry Pi algorithm is shared with the ESP32. The PWM signals which do the color mixing are calculated by a function when the value is received. The base color of red for zero

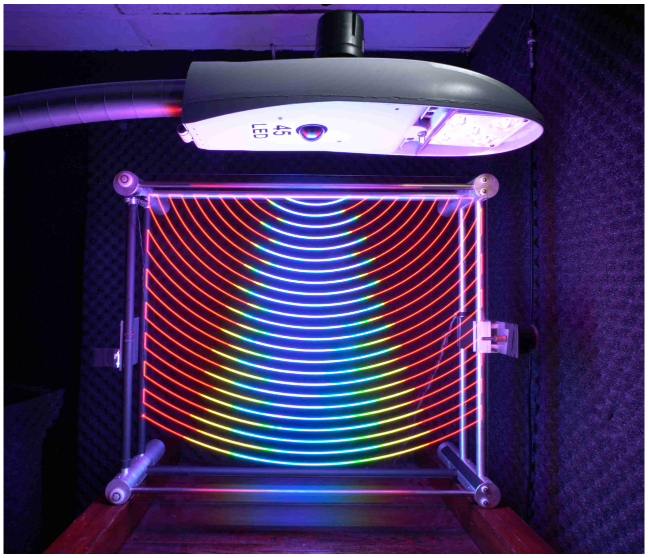

Figure 7: Unretouched photograph of the smart street light and metaveillographic mechanism showing the streetlight's built in camera and its capacity to sense. Note the slight hysterisis as the light source, moving in circular arcs, is both the sensor as well as the actuator, providing scientific and artistic integrity in the measurement. We can clearly see a physical phenomenon underlying the picture in the form of the hysteresis of even and odd arcs. Compare with figure 3.

detection was picked due to the similarity with a low voltage incandescent light as can be seen at the ends of the light trails in Fig 3.

4 G-CODE AND STEPPER MOTORS FOR HIGH SPATIAL RESOLUTION

Scientific instruments are used as the golden standard to measure and understand natural phenomena. The improved accuracy and precision of modern instruments enhance repeatability and validity of scientific experiments. If metaveillography is proposed as a scientific measurement to visualise the capacity of sensors to sense, then high spatial resolution and repeatability are mandatory criteria. It is for this reason that G-code, a G-code interpreter, and stepper motors are used to trace out the path in space. This setup is used in many computer-aided manufacturing machines like CNC mills and 3D printers. G-code is a common numerical control programming language that is used to program automated machining tools. For the purpose of metaveillance, a path of concentric circular arcs are traced which serves as the "canvas" to display the metaveillography of light.

The dimensions of the canvas and number of concentric circles are adjustable parameters. At first, the pattern starts at the centre of the y axis, and traces out semi-circles with increasing radius alternating between clockwise (using the "G2" command in G-code) and counterclockwise (using the "G3" command). The radius of each consecutive semi-circle is incrementally larger, depending on the number of concentric circles.

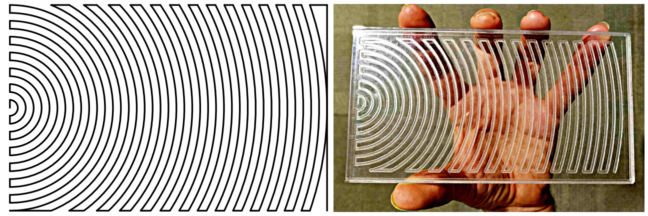

Figure 8: G-code trial using CNC. The advantage of using G-code is the portability of the code. It can be tested in several different ways. Here the spatial pattern was milled into a block of acrylic and passed around a classroom where metaveillography was being taught.

In order to help make the whole process more tangible, and to serve as a teaching aid in classroom lessons on metaveillography, this pattern was milled into an acrylic block for visualization as shown in Fig. 8.

We buit a robotic mechanism around the RepRap Arduino Mega Pololu Shield 1.4 (RAMPS 1.4) interfaced to the Arduino Mega, with the Repetier firmware, and Arduino+Shield combination. This setup is normally used for 3D printers. Together they form the open-loop controller which controls the stepper motors. Here 2 degrees of freedom were used for each 2D slice of the metaveillograph, i.e. controlling 2 stepper motors, and using 2 endstops. The stepper motors are 24V NEMA 23s which each are driven by a M542T Stepper motor Driver. To visualize the G-code path, we are using the Repetier-Host V2.1.3, which is a 3D printing slicer. The system is completed with a full graphic smart controller that contains a SD-Card reader, a rotary encoder and a 128 x 64 dot matrix LCD display. Furthermore all actions like calibration, axis movement, etc., can be done by just using the rotary encoder on the Smart Controller. Thus our experiments can be controlled and automated using G-code which can be stored on the SD card.

5 ULTRASOUND METAVEILLANCE

Microphones and ultrasonic sensors are also becoming more important in both IoT and wearable technology, particularly in the space of mobility aids for the visually impaired. We created a Doppler sonar sensing system that allows the wearer to hear objects in the room and mentally construct a visual map of their surroundings as they move. It is important that such sensors be calibrated well, such as measuring the signal attenuation drop-off due to range and angular offset, so we used metaveillance as a design tool to help us design the wearable system while being able to see its metaveillograph. To demonstrate this, we created a metaveillograph of the sensing capabilities of our ultrasonic sensor. A 40 kHz square wave signal was fed into both the emitter and the in-phase reference input of a low-cost miniature lock-in amplifier that we designed and built. A second signal is a 90° phase shift of the first signal and is fed into the quadrature reference of the lock-in amplifier. Finally, the signal from the ultrasonic sensor is fed into the signal input of the lock-in amplifier. This will produce a complex-valued output in the form of an in-phase and quadrature component which can be used to compute the magnitude and phase of the signal. See Fig 9.

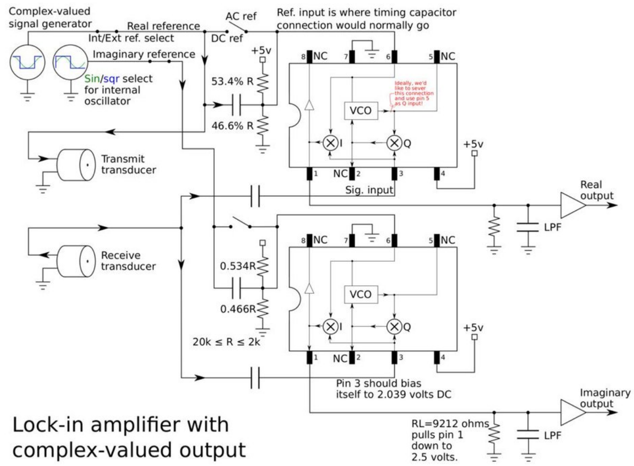

Figure 9: Schematic of the wearable miniature Lock-in amplifier designed by the authors for a low-cost seeing aid for the blind. See https://www.instructables.com/member/SteveMann/

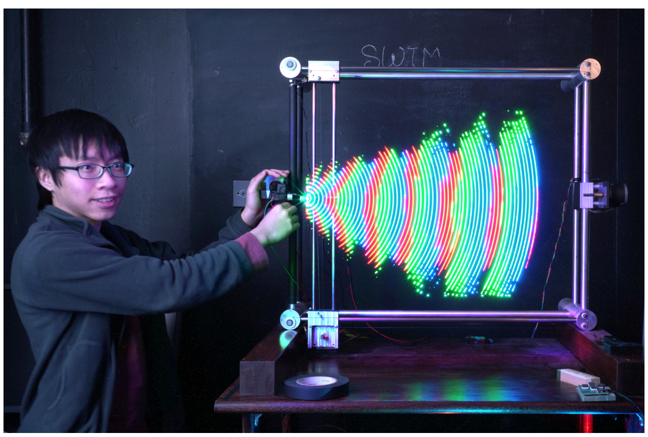

Figure 10: Photograph of ultrasonic sensor. Red, green and blue bands show phase information.

These values are then used to decide how to light up an RGB LED to visualize the metaveillance wavefunction [31]. In software, the square of the magnitude was computed by summing the squares of the in-phase and quadrature components. The phase was computed by taking the arc-tangent of the quadrature over the in-phase component. (The atan2 function was used which has a range of e $(-\pi, \pi)$. The magnitude was used to establish a cutoff threshold for the LED while the phase was visualized by dividing the range of $(-\pi, \pi)$ into three and mapping each part to the red, green, and blue intensities of the LED, as shown in Fig 10.

6 RESULTS AND DISCUSSION

The proposed method facilitates a deeper understanding of sensors and their ability to sense. With the increasing demand of these devices in the market, it is valuable to support any specification that includes a graphical depiction with photographic evidence, so the customers can have a clear idea of what are they buying. By clearly showing a camera's field of view imprinted in the real world, the public is able to understand and compare the capabilities of different cameras, in an intuitively visual manner. Moreover, this has forensic value as well as a veracity that will help develop trust in sensing and sensors.

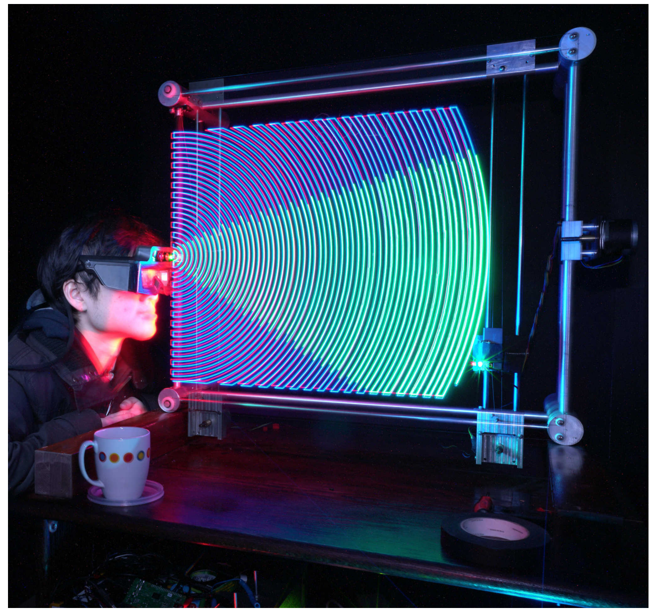

Figure 11: Photograph of the sensory capacity of an augmented reality headset.

7 METAVEILLANCE: SOUSVEILLANT SYSTEMS FOR A BETTER FUTURE

In addition to allowing us to sense how a camera can sense, we can also sense the sensing of multiple cameras in overlapping zones. Another potential use in the automotive industry is the testing of sensors and actuators in self driving cars. The necessity of a standard for these new components is emerging quickly. The result will be a simple photographic documentation of a vehicle's capacity to sense, and this will allow end-users to easily understand a vehicle's sensory capacity. Another application is in the testing of human vision where we use SSVEP or CTVEP (Chirplet Transform Visual Evoked Potentials to "SWIM-out" a human's capacity to see, so that it, together with the human, can be photographed. This can also be done using a VR headset – VREP™= Virtual Reality Evoked Potentials. See the Keynote paper, "Sensors, Integrity, and Trust...".

Computers and cars and things in general are being designed so that they are easier to use, and so that they take less intelligence to use. This creates an inherent risk: "Design-for-Stupidity" (as it is pejoratively sometimes called) is design against intelligence – it alienates the more educated user. In some ways, intelligence is actually a disability in the modern world of the increased complexity implemented to "dumb things down". In the same way that we must provide accessibility to the blind, and deaf, we must also provide accessibility to those afflicted with intelligence, and especially those who have difficulty working with things they can't fully understand. Metaveillance is a step forward to what we call "Sousveillant

Systems", i.e. systems that are self-revealing to end-users. This represents an important step forward to help educate the world about how things work, especially in the era of surveillance which puts emphasis on secrecy and concealment. We need to return to the classic Greek concept of alethia (a truth based on unconcealedness).

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