Sensing of the Self, Society, and the Environment

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***Abstract*—We propose a novel sensemaking taxonomy, and a working wearable computing system within that taxonomy, to help people sense and understand the world around them. This unified system and taxonomy organizes the world of sensors and sensory experience into the following: (A) Self-and-Technology; (B) Self-and-Society; and (C) Self-and-Environment. This wearable system, which we named "Vironment™", embodies a suite of functionalities which demonstrate each of the three presented levels. The taxonomy helps in understanding the line between self, society, and the world around us, while Vironment extends the wearer's sensing capabilities in these three areas.**

***Index Terms*—Wearable computing, Wearables, Sensing, Mobile computing, Social distance, Contact tracing, Sousveillance.**

I. Introduction

Wearable sensing technologies can create new and extended human sensing capabilities which work similarly to sensory organs. This concept is explored in Fig 1. The realization that our technologies are as much a part of us as our sensory organs begs the question: *Where is the boundary between the self, others, and the environment?*

The human mind may be regarded as one or more feedback loops. The human may similarly be regarded as a feedback loop between the mind and body, i.e. efferent nerves carry signals from the mind to the body, and afferent nerves carry signals from the body to the mind [1], thus completing a closed loop control system [2], [3], shown in leftmost Fig. 1.

Humanistic Intelligence (HI) [4], also known as Wearable AI [5], is a framework for wearable computers and other forms of closed-loop feedback between human and machine.

HI systems are already natural to our thinking. For example, in a parking lot when two cars collide, one driver will often say "You hit me!" rather than "Your car hit my car.". Technologies like shoes, wearable computers, bicycles, and automobiles are technologies that "become part of us." This symbiosis between human and machine is often referred to as a "humachine" [6], "cyborg" [3], bionic, or "augmented human". They typically consist of sensors in the machine and our human senses forming a feedback loop. HI feedback loops can be understood and classified according to the following nested taxonomy:

- **A.** Self and technology (e.g. combined human+machine);
- **B.** Self and society (interaction between humans, humachines, etc.), which includes self and technology;
- **C.** Self and the environment (interaction between the augmented human and the natural or built environment, e.g. cyborg-city interaction), which includes self, technology, and society.

This human-centered taxonomy considers the sensory information available at three key levels as shown in Fig 1).

To explore this taxonomy, we present a 3D printed, low-cost, low-power, head-worn wearable hardware system [7] [8] [9] [10] [11] based upon the OpenEyeTap design [12], which we name "Vironment™". This system embodies a number of functionalities which extend the wearer's sensory and computational abilities on the levels of Self-and-Technology, Self-and-Society, and Self-and-Environment.

II. Self + {Tech, Society, Environment}

A. Self and Technology

The most core aspect of understanding one's reality is understanding the self. Modern sensor technology offers an unprecedented method of understanding one's physiological condition in real time, a core attribute of Humanistically Intelligent systems.

1) Vitalveillance EyeTap: Vitalveillance is a wearable functionality of the Vironment wearable that senses the wearer's health by continually observing four vital signs: blood pressure, heart rate, respiration rate, and temperature. The device saves these health metrics in a database that can be reviewed to track one's physical and mental health, and correlate those readings with their day-to-day activities. This system provides the wearer with self-sensing capabilities in an HI feedback loop that becomes an extension of the self, giving rise to distributed "little data" health sousveillance [13].

Vironment houses two MAX30100 photoplethysmogram (PPG) [14], [15] sensors, one LM35 temperature sensor, and one MMA7361LC accelerometer [12], [16]. These sensory signals are combined and processed to estimate temperature, blood pressure, pulse, and respiration rate. [17]. Blood pressure (BP) and heart rate (HR) are key biometrics that are highly relevant to physiological condition measurement and response analysis [18]. Pulse transit time (PTT) is a metric commonly used as a correlate of blood pressure [19]. PTT is the time for the pressure wave from a heart beat to propagate along a blood vessel. The following model is fit for each participant to infer blood pressure from PTT [20]:

$$BP = \frac{-2}{\alpha}\ln(PTT) + \frac{1}{\alpha}\ln\frac{2r\rho L^2}{hE_0},$$

where α is the Wormsley number, PTT is the pulse transit time, r is the vessel radius, L is the vessel length, h is the vessel wall thickness, E_0 is the zero-pressure modulus of elasticity for the vessel wall, and ρ is the blood density [21].

PPG data is first bandpass filtered to a range of 4-7 Hz before peak detection is applied to both input signals [22] [21]. PTT is calculated from the difference in peak times between the sensors while heart rate is deduced via peak distance detection from a single PPG signal.

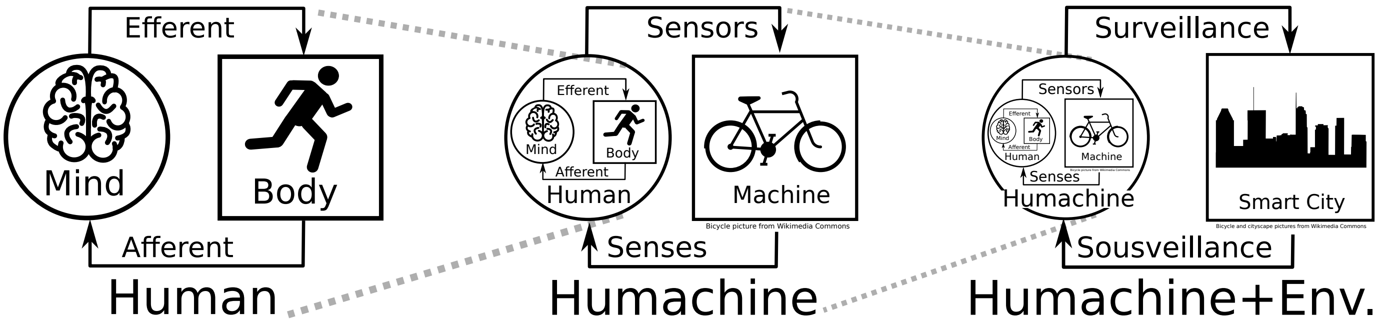

Fig. 1: The human ("Human" above) may be regarded as a closed feedback loop formed by the mind and body. Similarly a humachine [6] ("Humachine" above) is a closed-loop feedback system between human and machine. Our proposed system, "Vironment", facilitates interaction between a humachine and their urban or natural environment.

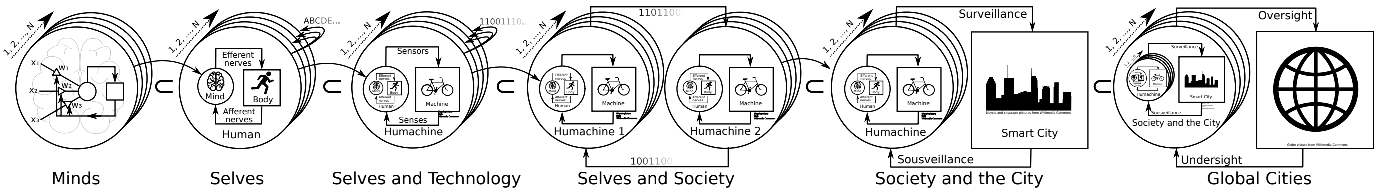

Fig. 2: Expanding upon the concept presented in Fig. 1, the mind itself may be regarded as containing elements of closed-loop feedback, i.e. we can see a self-similar (fractal) nature inherent in Mind, Human, Humachine, and (urban) Environment. Here we acknowledge that there is not just one self, but many selves in a society, i.e. each person's mind, body, etc. Likewise there are multiple cities and other similar entities in the global society. Thanks to Faraz for help with this figure.

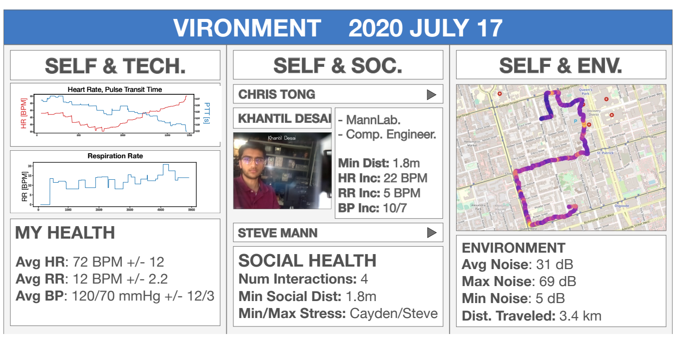

Fig. 3: The Vironment wearable user interface, displaying technologies operating at all three levels of the taxonomy.

Fig. 4: Left image: Vironment reading blood pressure, pulse, respiration rate, and temperature. Right image: Social-distancing sonar necklace prototype which is an optional accessory for the Social Distancer function of Vironment.

Respiration rate (RR) is another highly relevant biometric. It is well understood that respiration can impart a range of measurable variations to blood-pulse waveforms [23] as collected by PPG. Of these variations there are three types: amplitude modulation, ie. respiration-induced amplitude variation (RIAV), frequency modulation, ie. respiration-induced frequency variations (RIFV), and additive mixing, ie. respiration-induced intensity variation (RIIV) [24] [25]. The RIIV-based algorithm consists of an adaptive digital comb filter which uses peak detection to remove the blood pulse waveform harmonics, a digital low-pass filter which extracts the range of human respiration (0.13-0.83 Hz), and RR peak detection [20]. Since RIAV is amplitude modulation (AM) imparted by the respiration signal, the RIAV-based algorithm uses quadrature demodulation to extract RR. The demodulation uses estimated pulse rate (PR) to adaptively filter the upper side-band of the AM signal before demodulating the PR carrier down to base-band (0 Hz) by mixing the resulting signal with quadrature and in-phase PR carriers [26]. RR is then extracted from the demodulated upper-side band by filtering the RR range and performing peak-detection. Averaging of the RR calculated from RIIV and RIAV enabled better RR estimation accuracy compared to either of the individual respective estimations.

B. Self and Society

Wearable are not only about the self, but also about society. Vironment performs two functions at the Self-and-Society level: a wearable face recognizer (Section B.1) and Social Distancer (Section B.2).

1) Wearable Face Recognizer: The wearable face recognizer senses social activity and enhances social abilities of the wearer. This functionality of Vironment recognizes individuals and provides wearers with a head-up display showing names of the people they know around them, reminders they made about them, notes from previous conversations, and where and when they previously met. Face recognizers are well known in the literature [27] and have utility as extended social memory.

A major component of mental health and well being is determined by the quality of an individual's social life, i.e. their relationships. Social visual memory enhancement thus helps the wearer improve and understand their mental health.

The wearable face recognizer consists of Vironment streaming video to a backend cloud server [12]. Upon receiving a live video stream, the backend server identifies faces and returns the names of any individual who appears in the image. Recognition of faces relies on a personal face database that is built by and, by default, is private to the user, and protected by our Priveillance™ system. Based on the people identified in the video, the wearable face recognizer overlays relevant information directly onto the users' vision using the Vironment's EyeTap display. Thus the wearable face recognizer provides the wearer with Extended Intelligence [28] in regards to social memory recall [29].

2) Social Distancer: The Social Distancer is a neck-worn accessory to Vironment that serves to enhance the wearer's ability to maintain a safe social distance during pandemics (see Fig 5). The Social Distancer exists at the Self-and-Society level of our taxonomy, and serves the need of physical health by helping prevent the spread of disease. This is accomplished by sensing others and sensing the environment around the wearer, providing live updates if anyone breaks social distance guidelines (e.g. coming closer than 2 metres or 6 feet, as specified in [30]).

The Social Distancer function of Vironment is equipped with 12 sonar sensors equally spaced in a circular array, with the sensors numbered similarly to a clock face, with sensor #12 facing forward, sensor #3 on the right, sensor #6 at the back, etc. The system senses the presence of people near the wearer and displays this live on the Vironment system. An alert (a bright light and loud horn) is actuated whenever someone breaks social distance. The necklace was designed in Fusion360 and 3D printed in two pieces. The pieces are connected together by a hinge which allows the user to easily put on and take off the device. On the side without a hinge there is a locking mechanism consisting of two latches that close down on a pin. The sensory electrical system consists of 12 HC-SR04 Ultrasonic sensors which are rapidly switched using 4 MC14051B analog multiplexers. The output of these sensors are read by an Espressif ESP-32 microcontroller, which computes distances and communicates with Vironment. We also built a more refined version with each transducer being both a transmitter and receiver.

While the wearable face recognizer helps us understand our social place in society, the Social Distancer helps us understand our physical place in society.

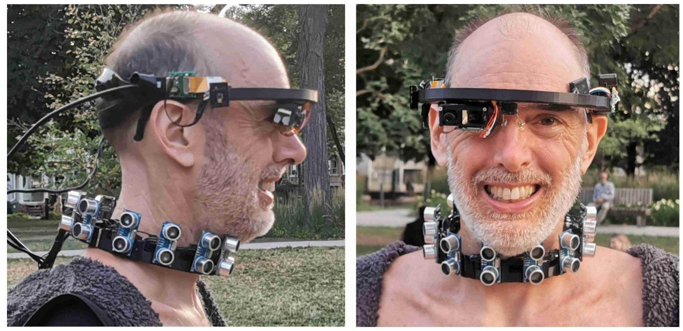

Fig. 5: The Sonar Social Distancer streaming data to Vironment [31].

C. *Self and Environment*

In order for people to fully perceive and understand the world around them, the final element of the taxonomy, Self-and-Environment, must be sensed and understood. Therefore, Vironment measures not only the wearer's body and the bodies of others around them, but also their environment.

1) Ambient Noise Level Mapping: The ambient noise level mapper is a functionality of Vironment that tracks and maps the amount of noise pollution in the environment of the wearer. See Fig 3 top right image. While users move through their environment, the root-mean squared (RMS) value of a live microphone output is logged along with GPS coordinates and plotted onto a map. In addition to providing a simple understanding of noise pollution, this data can also serve as a basic indication of air pollution levels in the city [32]. Vironment's Self-and-Environment capabilities help us create a comprehensive understanding of the environment where Vironment wearers interact.

2) Curitree™: We regard security as the trunk of a tree having surveillance branches like public safety, crime prevention (sub-branches robbery prevention, violence prevention, ...), operational efficiency, ... The tree is rooted in sousveillance, with roots like personal safety, "suicurity" (corruption prevention), personal efficiency (sub-roots VMP, seeing aid, ...), ...

III. Conclusion

We proposed a taxonomy and wearable computer system based on this taxonomy to help people sense and understand the world around them on the levels of (A) Self-and-Technology, (B) Self-and-Society, and (C) Self-and-Environment. We named our system "Vironment". Vironment augments the user's ability to sense and understand all levels of the taxonomy. It senses our own physiological condition, the presence and identity of those around us, and our environment (urban, natural, etc.). This enables a comprehensively extended sensory experience for the wearer. The proposed framework and the functional system helps us understand the often blurry lines between the three levels of the taxonomy while meaningfully enhancing the wearer's senses.

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