Wearable Computing: Towards Humanistic Intelligence

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Abstract

Humanistic Intelligence (HI) is a new signal processing framework in which (1) intelligence arises by having the human being in the feedback loop of the computational process, and (2) the processing apparatus is inextricably intertwined with the natural capabilities of the human mind and body. Rather than trying to emulate human intelligence, HI recognizes that the human brain is perhaps the best neural network of its kind, and that there are many new signal processing applications, within the domain of personal cybernetics, that can make use of this excellent but often overlooked processor. The emphasis of this Special Issue is on Intelligent Systems based on wearable computers embodying HI, to take a first step toward an intelligent wearable signal processing system that can facilitate new forms of communication through collective connected H.I..

Keywords

Humanistic Intelligence, Artificial Intelligence, Intelligent Systems, Intelligent Signal Processing, Human factors, Mobile communication, Machine vision, Cybernetic sciences, Wearable Computing, Humanistic property protection.

I. Motivation

Over the past 20 years Wearable Computing has emerged as the perfect tool for embodying Humanistic Intelligence (HI). HI is defined as intelligence that arises from the human being in the feedback loop of a computational process in which the human and computer are inextricably intertwined.

It is common, within the field of Human Computer Interaction (HCI), to think of the human and computer as separate entities. (Indeed, this separateness is emphasized by the very terminology "HCI", e.g. listing the human and computer as separate entities that interact.) However, in the theory of HI, we prefer not to think of the wearer and the computer with its associated input/output apparatus as separate entities. Instead we prefer to regard the computer as a second brain, and its sensory modalities as additional senses, which through synthetic synesthesia are inextricably intertwined with the wearer's own biological sensory apparatus.

When a wearable computer functions in a successful embodiment of HI, the computer uses the human's mind and body as one of its peripherals, just as the human uses the computer as a peripheral. This reciprocal relationship, where each uses the other in its feedback loop, is at the heart of HI.

II. Introduction

H.I. is a new form of "intelligence" whose goal is to not only work in extremely close synergy with the human user, rather than as a separate entity, but more importantly, to arise, in part, because of the very **existence** of the human user [1]. This close synergy is achieved through a *user-interface* to signal processing hardware that is both in *close physical proximity* to the user, and is *constant*.

The constancy of user-interface (interactional constancy) is what separates this signal processing architecture from other related devices such as pocket calculators and Personal Digital Assistants (PDAs).

There are three fundamental operational modes of an embodiment of HI: Constancy, Augmentation, and Mediation. Firstly, there is a constantly of user interface, which implies an "always ready" interactional constancy, supplied by a continuously running operational constancy. Wearable computers are unique in their ability to provide this "always ready" condition which might, for example, include a

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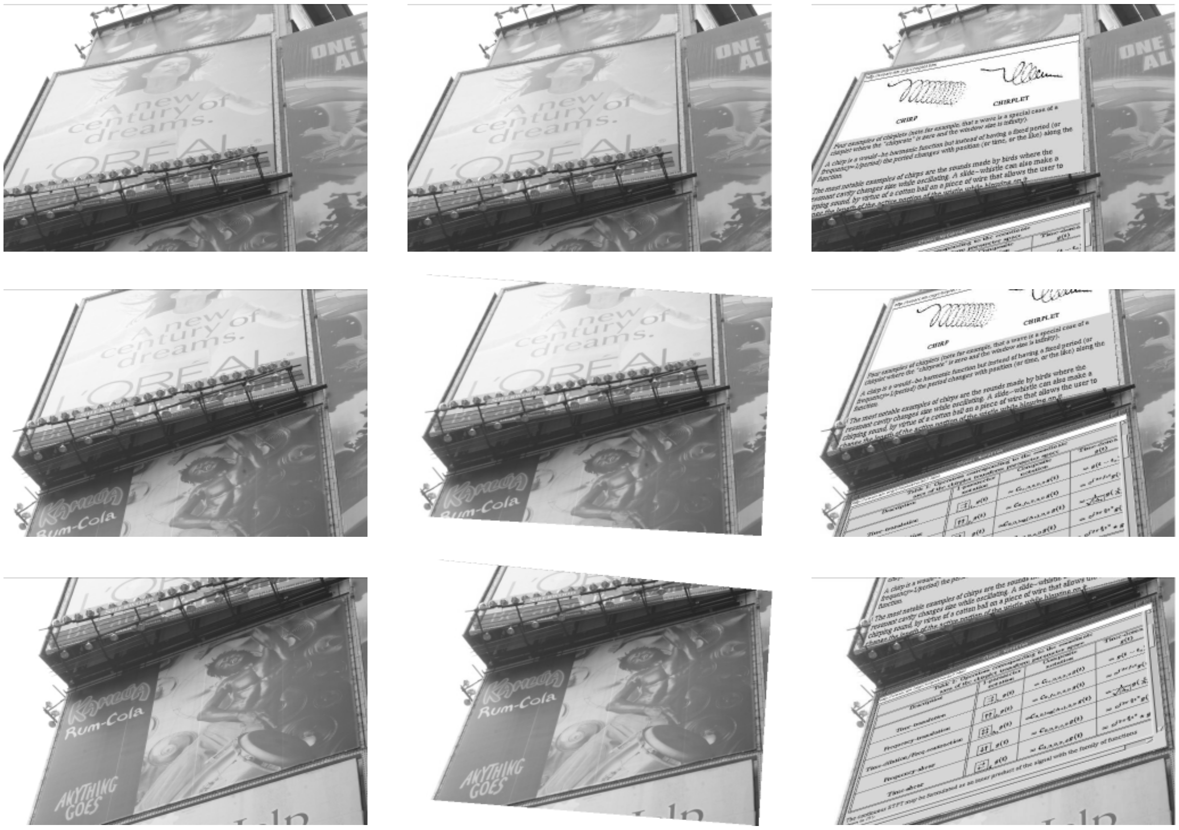


(a) (b) (c)

Fig. 1. The owner of a building or other real estate can benefit financially from erecting distracting and unpleasant (at least unpleasant to some people) advertising signs into the line of sight of all who pass through the space in **and** around his or her property. Such theft of solitude allows the owner to benefit at the expense of others who are victims of this theft. Legislation is one possible solution to this problem. Instead, however, a Diffusionist [2] approach is proposed, in the form of a simple engineering solution, in which the individual may filter out unwanted real–world spam. Since the apparatus, when functioning as a Reality Mediator, has the potential to create a modified perception of visual reality (e.g. mediated environments, as in (b)), it can function as a visual filter to filter out the advertising in (a), and replace it with useful subject matter in (c). Such a computer-mediated Intelligent Signal Processing system is an example application of H.I..

retroactive video capture for a face recognizing reminder system. After-the-fact devices like traditional cameras and palmtop organizers cannot provide this retroactive computing capability. Secondly, there is an augmentational aspect in which computing is NOT the primary task. Again, wearable computing is unique in its ability to be augmentational without being distracting to a primary task like navigating through a corridor, or trying to walk down stairs. Thirdly, there is a mediational aspect in which the computational host can protect the human host from information overload, by deliberately diminished reality, such as by visually filtering out advertising signage and billboards (Fig 1).

Implicit in the Augmenting and Mediating modes is a spatiotemporal contextual awareness from sensors (wearable cameras, microphones, etc.).

As an example of H.I., it is now possible to build a miniature nearly invisible apparatus, (called an EyeTap [1] device, as shown in Fig 2) for lifelong video capture, that can also predict or infer and distinguish from among threat or opportunity based on previously captured material. Such computing blurs the line between remembering and recording, as well as the line between thinking and computing. Thus we will need a whole new way of studying these new human-based intelligent systems. Such an apparatus has in fact already raised various interesting privacy and accountability issues. Thus HI necessarily raises a whole new set of humanistic issues not previously encountered in the field of Intelligent Systems.

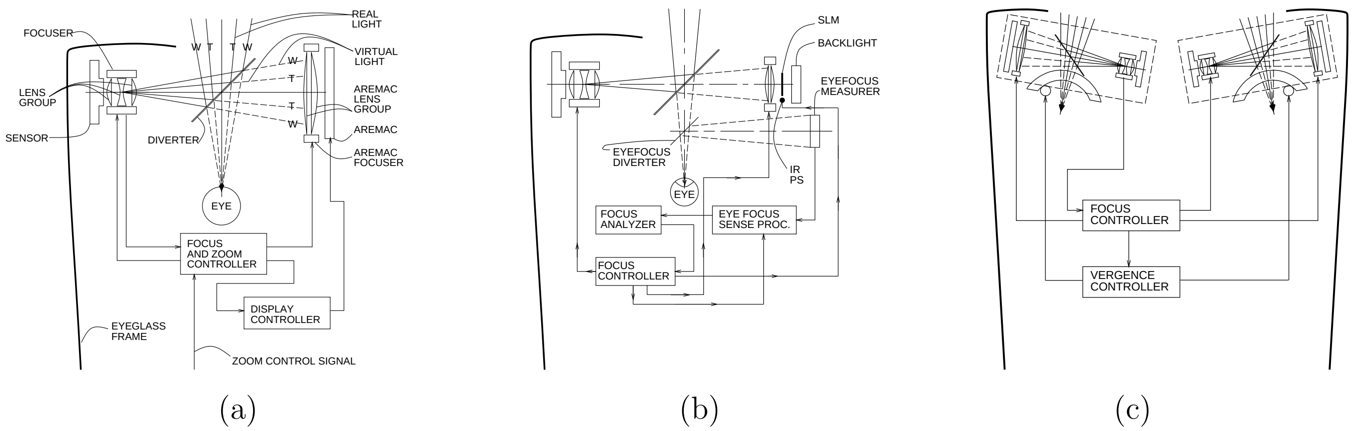


Fig. 2. EyeTap devices are devices that cause the eye itself to, in effect, behave as if it were both a camera and a display. Such devices naturally embody Humanistic Intelligence because (1) intelligence arises by having the human being in the feedback loop of the computational process, and (2) the EyeTap apparatus is worn constantly, and in close proximity to the eye, and is inextricably intertwined with the natural capabilities of the human mind and body. The mathematical coordinate transformations in Fig 1(b) arise from the system's awareness of the gaze pattern of the wearer, such that this intelligent system is *activity driven*. Areas of interest in the scene will attract the attention of the human operator, so that he or she will spend more time looking at those parts of the scene. In this way, those parts of the scene of greatest interest will be observed with the greatest variety of quantization steps (e.g. with the richest collection of differently quantized measurements), and will therefore, without conscious thought or effort on the part of the wearer, be automatically emphasized in the composite representation [1]. This natural *foveation* process arises, not because the *Artificial Intelligence* (AI) problem has been solved and built into the EyeTap, so that it knows what is important, but simply because the EyeTap is using the operator's brain as its guide to visual saliency. Because the EyeTap does not take any conscious thought or effort to operate, it resides on the human host without presenting the host with any burden, yet it benefits greatly from this form of H.I.. Depth tracking in the Eye Tap system is achieved by having a device called an aremac [1], and a camera both focused together by a single focus control input, either manual or automatic. Solid lines denote real light from subject matter, and dashed lines denote virtual light synthesized by the aremac. (a) Aremac focus controlled by autofocus camera. When the camera focuses to infinity the aremac focuses so that it presents subject matter that appears as if it is infinitely far. When the camera focuses close, the aremac presents subject matter that appears to be at the same close distance. A zoom input controls both the camera and aremac to negate any image magnification and thus maintain the Eye Tap condition. Rays of light defining the widest field of view are denoted W. Rays of light defining the narrowest field of view are denoted T (for "Tele"). Note that the camera and aremac fields of view correspond. (b) Aremac and camera focus both controlled by eye focus. An eyefocus measurer (by way of a beamsplitter called the eyefocus diverter) obtains an approximate estimate of the focal distance of the eye. Both the camera and aremac then focus to approximately this same distance. (c) Focus of right camera and both aremacs (as well as vergence) controlled by autofocus camera on left side. In a two eyed system, it is preferable that both cameras and both aremacs focus to the same distance. Therefore, one of the cameras is a focus master, and the other camera is a focus slave. Alternatively, a focus combiner is used to average the focus distance of both cameras and then make the two cameras focus at equal distance. The two aremacs, as well as the vergence of both systems also track this same depth plane as defined by camera autofocus.

Successful embodiments of H.I. are intelligent signal processing systems that include the human as an integral part of the system.

Not only is the apparatus operationally constant, in the sense that although it may have power saving (sleep) modes, it is never completely shut down (dead as is typically a calculator worn in a shirt pocket but turned off most of the time). More important is the fact that it is also interactionally constant. By interactionally constant, what is meant is that the inputs and outputs of the device are always potentially active. Interactionally constant implies operationally constant, but operationally constant does not necessarily imply interactionally constant. Thus, for example, a pocket calculator, worn in a shirt pocket, and left on all the time is still not interactionally constant, because it cannot be used in this state (e.g. one still has to pull it out of the pocket to see the display or enter numbers). A wrist watch is a borderline case; although it operates constantly in order to continue to keep proper time, and it is conveniently worn on the body, one must make a conscious effort to orient it within one's field of vision in order to interact with it.

A. Why Humanistic Intelligence

At one time, people did not see the reason for having devices be operational and interactionally constant, and this shortsighted view led to the development of a large number of hand-held or so-called "portable" devices. In this Special Issue, however, we will see why it is desirable to have certain personal electronics devices, such as cameras and signal processing hardware, be on constantly, for example, to facilitate new forms of intelligence that assist the user in new ways.

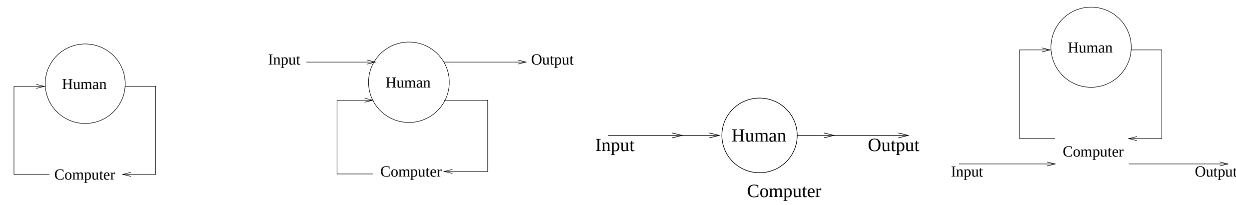
Devices embodying HI are not merely intelligent signal processors that a user might wear or carry in close proximity to the body, but instead, are devices that turn the user into part of an intelligent control system where the user becomes an integral part of the feedback loop.

B. Humanistic Intelligence does not necessarily mean "user-friendly"

Devices embodying HI often require that the user learn a new skill set, and are therefore not necessarily easy to adapt to. Just as it takes a young child many years to become proficient at using his or her hands, some of the devices that implement HI have taken years of use before they began to truly behave as if they were natural extensions of the mind and body. Thus, in terms of Human-Computer Interaction [3], the goal is not just to construct a device that can model (and learn from) the user, but, more importantly, to construct a device in which the user also must learn from the device. Therefore, in order to facilitate the latter, devices embodying HI should provide a constant user-interface — one that is not so sophisticated and intelligent that it confuses the user. Although the device may implement very sophisticated signal processing algorithms, the cause and effect relationship of this processing to its input (typically from the environment or the user's actions) should be clearly and continuously visible to the user, even when the user is not directly and intentionally interacting with the apparatus. Accordingly, the most successful examples of HI afford the user a very tight feedback loop of system observability (ability to perceive how the signal processing hardware is responding to the environment and the user), even when the controllability of the device is not engaged (e.g. at times when the user is not issuing direct commands to the apparatus). A simple example is the viewfinder of an EyeTap imaging system (Fig 2, which causes the eye itself to, in effect, be endowed with framing, a photographic point of view, and an intimate awareness of the visual effects of the eye's own image processing capabilities, even when pictures are not being captured or transmitted. Thus an intelligent system embodying HI puts the human operator in the feedback loop of the system's intelligence, even when the operator only wishes to use the apparatus occasionally. In particular, the apparatus is always running in background mode, even when it is not being "used". This constancy helps to keep the user adapted to the intelligent system.

A more sophisticated example of HI is a biofeedback-controlled EyeTap system, in which the biofeedback process happens continuously, whether or not a picture is actually being taken. In this sense, the user becomes one with the machine, over a long period of time, constantly adapted to the machine intelligence, even if the machine is only deliberately used (e.g. to actually take a picture) occasionally.

Humanistic Intelligence also suggests a new goal for signal processing hardware, that is, in a truly personal way, to directly assist, rather than replace or emulate human intelligence. What is needed to facilitate this vision is a simple and truly personal computational signal processing framework that empowers the human intellect. It should be noted that the H.I. framework which arose in Canada in the 1970s and early 1980s is in many ways similar to Engelbart's vision that arose in the 1940s while he was a radar engineer, but that there are also some important differences. Engelbart, while seeing images on a radar screen, envisioned that the cathode ray screen could also display letters of the alphabet, as well as computer generated pictures and graphical content, and thus envisioned computing as an interactive experience for manipulating words and pictures. Engelbart envisioned the mainframe computer as a tool for augmented intelligence and augmented communication, in which a



(a) (b) (c) (d)

Fig. 3. The three basic operational modes of devices that embody H.I.. (a) Signal flow paths for a computer system that runs continuously, constantly attentive to the user's input, and constantly providing information to the user. Over time, constancy leads to a symbiosis in which the user and computer become part of each other's feedback loops. (b) Signal flow path for augmented intelligence and augmented reality. Interaction with the computer is secondary to another primary activity, such as walking, attending a meeting, or perhaps doing something that requires full hand–to eye coordination, like running down stairs or playing volleyball. Because the other primary activity is often one that requires the human to be attentive to the environment as well as unencumbered, the computer must be able to operate in the background to augment the primary experience, for example, by providing a map of a building interior, or providing other information, through the use of computer graphics overlays superimposed on top of the real world. (c) Successful embodiments of H.I. can be used like clothing, to encapsulate the user and function as a protective shell, whether to protect us from cold, protect us from physical attack (as traditionally facilitated by armour), or to provide privacy (by concealing personal information and personal attributes from others). In terms of signal flow, this encapsulation facilitates the possible mediation of incoming information to permit solitude (e.g. filtering unwanted advertising as shown in Fig 1, or managing and screening incoming calls to prevent a mobile phone from ringing during a business meeting), and the possible mediation of outgoing information to permit privacy. It is not so much the absolute blocking of these information channels that is important; it is the fact that the wearer can control to what extent, and when, these channels are blocked, modified, attenuated, or amplified, in various degrees, that makes H.I. much more empowering to the user than other similar forms of portable computing. (d) An equivalent depiction of encapsulation (mediation) redrawn to give it a similar form to that of (a) and (b), where the encapsulation is understood to comprise a separate protective shell.

number of people in a large amphitheatre could interact with one another using a large mainframe computer[4] [5].

While Engelbart himself did not realize the significance of the personal computer, his ideas are certainly embodied in modern personal computing. What is presented in this Special Issue is a variety of research attempts at realizing a similar vision, but with the computing re–situated in a different context, namely the truly personal space of the user. The idea here is to move the tools of augmented intelligence and augmented communication directly onto the body, giving rise to not only a new genre of truly personal computing, but to some new capabilities and affordances arising from direct physical proximity to the human body, allowing the feedback loop implicit in H.I. theory to develop. Moreover, a new family of applications arises, in which the body–worn apparatus facilitates an augmenting and mediating of the human sensory capabilities.

III. Theory of Humanistic Intelligence

Embodiments of H.I. will now be defined in terms of their three basic modes of operation, as illustrated in Fig 3:

• Constancy: The computer runs continuously, and is "always ready" to interact with the user. Unlike a hand-held device, laptop computer, or PDA, it does not need to be opened up and turned on prior to use. The signal flow from human to computer, and computer to human, depicted in Fig 3(a) runs continuously to provide a constant user–interface.

• Augmentation: Traditional computing paradigms are based on the notion that computing is the primary task. Intelligent Systems embodying H.I, however, are based on the notion that computing is NOT the primary task. The assumption of H.I. is that the user will be doing something else at the same time as doing the computing. Thus the computer should serve to augment the intellect, or augment the senses. The signal flow between human and computer, in the augmentational mode of operation, is depicted in Fig 3(b).

• Mediation: Unlike hand held devices, laptop computers, and PDAs, good embodiments of H.I. can encapsulate the user (Fig 3(c)). An apparatus embodying H.I. doesn't necessarily need to completely enclose us, but the basic concept of mediation allows for whatever degree of encapsulation might be desired, since it affords us the possibility of a greater degree of encapsulation than traditional portable computers. Moreover, there are two aspects to this encapsulation, one or both of which may be implemented in varying degrees, as desired:

– Solitude: The ability of an embodiment of H.I. to mediate our perception can allow it to function as an information filter, and allow us to block out material we might not wish to experience, whether it be offensive advertising, or simply a desire to replace existing media with different media. In less extreme manifestations, it may simply allow us to alter aspects of our perception of reality in a moderate way rather than completely blocking out certain material. Moreover, in addition to providing means for blocking or attenuation of undesired input, there is a facility to amplify or enhance desired inputs. This control over the input space is one of the important contributors to the most fundamental issue H.I., namely that of user empowerment.

– Privacy: Mediation allows us to block or modify information leaving our encapsulated space. In the same way that ordinary clothing prevents others from seeing our naked bodies, an embodiment of H.I. may, for example, serve as an intermediary for interacting with untrusted systems, such as third party implementations of digital anonymous cash, or other electronic transactions with untrusted parties. In the same way that martial artists, especially stick fighters, wear a long black robe or skirt that comes right down to the ground, in order to hide the placement of their feet from their opponent, a good embodiment of H.I. can also be used to clothe our otherwise transparent movements in both cyberspace and the real world. Although other technologies, like desktop computers, can, to a limited degree, help us protect our privacy with programs like Pretty Good Privacy (PGP), the primary weakness of these systems is the space between them and their user. It is generally far easier for an attacker to compromise the link between the human and the computer (perhaps through a so-called Trojan horse or other planted virus) when they are separate entities. Thus a personal information system owned, operated, and controlled by the wearer, can be used to create a new level of personal privacy because it can be made much more personal, e.g. so that it is always worn, except perhaps during showering, and therefore less likely to fall prey to attacks upon the hardware itself. Moreover, the close synergy between the human and computers makes it harder to attack directly, e.g. as one might look over a person's shoulder while they are typing, or hide a video camera in the ceiling above their keyboard. For the purposes of this Special Issue, it should be understood that privacy is not so much the absolute blocking or concealment of personal information, but it is the ability to control or modulate this outbound information channel. Thus, for example, one may wish certain people, such as members of one's immediate family, to have greater access to personal information than the general public. Such a family–area–network may be implemented with an appropriate access control list and a cryptographic communications protocol.

Because of the ability to encapsulate us, e.g. in embodiments of H.I. that are actually articles of clothing in direct contact with our flesh, such an apparatus may also be able to make measurements of various physiological quantities. Thus the signal flow depicted in Fig 3(a) is also enhanced by the encapsulation as depicted in Fig 3(c). To make this signal flow more explicit, Fig 3(c) has been redrawn, in Fig 3(d), where the computer and human are depicted as two separate entities within an optional protective shell, which may be opened or partially opened if a mixture of augmented and mediated interaction is desired.

Note that these three basic modes of operation do not necessarily need to be mutually exclusive in the sense that the first is embodied in both of the other two. These other two are also not necessarily meant to be implemented in isolation. Actual embodiments of H.I. typically incorporate aspects of both augmented and mediated modes of operation. Thus H.I. is a framework for enabling and combining

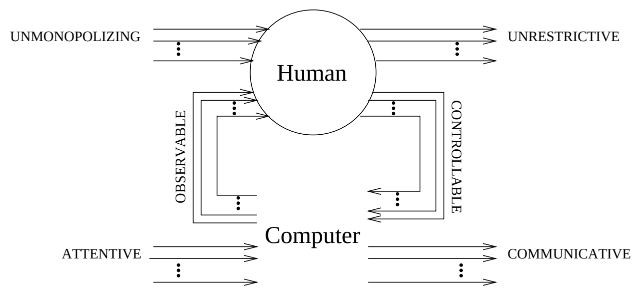


Fig. 4. The six signal flow paths for intelligent systems embodying H.I.. These six signal flow paths each define one of the six attributes of H.I..

various aspects of each of these three basic modes of operation. Collectively, the space of possible signal flows giving rise to this entire space of possibilities, is depicted in Fig 4. The signal paths typically comprise vector quantities. Thus multiple parallel signal paths are depicted in this figure to remind the reader of this vector nature of the signals.

A. The six basic signal flow paths of H.I.

There are six informational flow paths associated with this human–machine symbiosis. These signal flow paths each define one of the basic underlying principles of H.I., and are each described, in what follows, from the human's point of view. Implicit in these six properties is that the intelligent system is both operationally constant and personal (inextricably intertwined with the user). The six basic properties are:

1. **UNMONOPOLIZING of the user's attention**: it does not necessarily cut one off from the outside world like a virtual reality game or the like does. One can attend to other matters while using the apparatus. It is built with the assumption that computing will be a secondary activity, rather than a primary focus of attention. In fact, ideally, it will provide enhanced sensory capabilities. It may, however, facilitate mediation (augmenting, altering, or deliberately diminishing) these sensory capabilities.
2. **UNRESTRICTIVE to the user**: ambulatory, mobile, roving, one can do other things while using it, e.g. one can type while jogging, running down stairs, etc.
3. **OBSERVABLE by the user**: It can get the user's attention continuously if the user wants it to. The output medium is constantly perceptible by the wearer. It is sufficient that it be almost–always–observable, within reasonable limitations such as the fact that a camera viewfinder or computer screen is not visible during the blinking of the eyes.
4. **CONTROLLABLE by the user**: Responsive. The user can take control of it at any time the user wishes. Even in automated processes the user should be able to manually override the automation to break open the control loop and become part of the loop at any time the user wants to. Examples of this controllability might include a "Halt" button the user can invoke as an application mindlessly opens all 50 documents that were highlighted when the user accidentally pressed "Enter".
5. **ATTENTIVE to the environment**: Environmentally aware, multimodal, multisensory. (As a result this ultimately gives the user increased situational awareness).
6. **COMMUNICATIVE to others**: Successful embodiments of H.I. can be used as a communications medium when the user wishes. Expressive: Successful embodiments of H.I. allow the wearer to be expressive through the medium, whether as a direct communications medium to others, or as means of assisting the user in the production of expressive or communicative media.

IV. Outline of the Special Issue

We begin with a very profound and visionary paper in which Smailagic *et al.* provide a background for context aware computing, along with some very practical examples of Humanistic Intelligence implemented in such forms as a Portable Help Desk, etc.. This work comes out of CMU's SEI, under the direction of Dan Siewiorek, who has been working in the field of wearable computing for many years, together with researchers at IBM's Watson Research Center.

This paper marks an interesting departure from their previous work in the areas of military equipment maintenance applications, and suggests a branching out into applications more suitable for mainstream culture. Wearable computing has gone beyond the military industrial complex, as we are at a pivotal era where it is about to emerge to affect our daily lives.

The authors recognize the importance of privacy and solitude issues, and formulate the notion of a "Distraction Matrix" to characterize human attentional resource allocation.

Cheng and Robinson also look at an application that focuses on the mainstream consumer culture, that also gives us a glimpse into how H.I. could affect our daily lives. Their effort is in the area of context awareness through visual focus, with a particular emphasis on recognition of visual body cues, from the first person perspective of a personal imaging system. They provide two concrete examples, namely that of a personal memory system for playing the piano, and a system for assisting in ballroom dancing. This work shows us further examples of how wearable computers have become powerful enough to perform vision-based intelligent signal processing.

Esa provides a good tutorial on context awareness, with a good overall introduce to concepts and terminology. The paper also provides insight into the issues of Smart Clothing as embodiment of H.I., and how the user functions as part of the computational environment.

Sumi and Nishida put context awareness in a spatiotemporal global framework, with computer-based human communication. With conversational context, the system serves to illustrate how H.I. can serve as a human-human communications medium, mediated by wearable computer systems.

Ross provides an application of H.I. for assistive technology. Beyond the military industrial complex, the early adopters of H.I. may well be those with a visual impairment, or other impairment. It is for this sector of the population that wearable computing can make a major difference within the context of a person's daily life.

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I still need a copy of the final papers:

- 113787 (atalay, volkan, on glyphs, character stroke recognition, etc.); and
- 113790 (genso, headset...)

so that I can put these two papers in their final form, into context.

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V. Steps toward H.I.

H.I. is characterized by processing hardware that is inextricably intertwined with a human being to function as a true extension of the user's mind and body. This hardware is **constant** (always on, therefore its output is always observable), **controllable** (e.g. is not merely a monitoring device attached to the user, but rather, it takes its cues from the user), and is **corporeal** in nature (e.g. tetherless and with the point of control in close proximity to the user so as to be perceived as part of the user's body).

Furthermore, the apparatus forms a symbiotic relationship with its host (the human).

What differentiates HI from what some have said to be a similar idea called environmental intelligence (ubiquitous surveillance, *ubiquitous computing* [6], reactive rooms [7], and the like), is that there is no guarantee environmental intelligence will be present when needed, or that it will be in control of the user. Instead, HI provides a facility for intelligent signal processing that travels with the user.

Furthermore, because of the close physical proximity to the user, the apparatus is privy to a much richer multidimensional information space than that obtainable by environmental intelligence.

Systems embodying HI are:

- ACTIVITY DRIVEN and ATTENTION DRIVEN: Salience is based on the computer's taking information in accordance with human activity. For example, in a visual system (such as EyeTap), visual salience comes from the human; the computer is doing the processing but taking cue from the wearer's activity. Further processing on the image measurements thus reflect this saliency, so that the system adapts to the manner in which it is used.
- ENVIRONMENTALLY AWARE: Situated awareness arises in the context of both the wearer's environment and his/her own biological quantities which, through the wearer's own mind, body, and perceptual system, also depend on the environment.
- INEXTRICABLY INTERTWINED with the human; SITUATED: Because of the close feedback loop, the processor automatically uses the wearer's sense of salience to help it, so that the machine and human are always working in parallel.

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