Cost-effective Wearable Sensor to Detect EMF

Cati Vaucelle
MIT Media Lab
20, Ames Street
Cambridge, MA 02139 USA
cati@media.mit.edu

Joseph A. Paradiso
MIT Media Lab
20, Ames Street
Cambridge, MA 02139 USA
joep@media.mit.edu

Hiroshi Ishii
MIT Media Lab
20, Ames Street
Cambridge, MA 02139 USA
ishii@media.mit.edu

CHI 2009, April 4 – 9, 2009, Boston, MA, USA
ACM 978-1-60558-246-7/09/04.

Abstract
In this paper we present the design of a cost-effective wearable sensor to detect and indicate the strength and other characteristics of the electric field emanating from a laptop display. Our Electromagnetic Field Detector Bracelet can provide an immediate awareness of electric fields radiated from an object used frequently. Our technology thus supports awareness of ambient background emanation beyond human perception. We discuss how detection of such radiation might help to "fingerprint" devices and aid in applications that require determination of indoor location.

Keywords
Wearable sensor, ambient signals, capacitive sensor, EMF.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Before medical technology, people feared what was inside of the body and because of their ignorance attributed diseases such as epilepsy to divine interventions [17]. Now that medical technology exists, people know what the body is made of, and by knowing and visualizing it, they may be relieved from their fear

of the unknown. *Inside the living body* by Stephen Marsh is a movie that shows how the body transforms as it ages. Its goal is to relieve people from body anxiety as they gain control of what was not perceptively accessible. Today, many people fear electromagnetic fields. They believe (most probably exaggeratedly) that ambient fields can negatively influence their health. Perhaps, by visualizing the presence of common electromagnetic (EM) fields, users might feel in control of difficult-to-perceive information and transcend their fear, beginning the process of recognizing and moving beyond fear. An analogy might be found in the cheap RF power meters that are sold to enable people to gauge radiation leakage from their microwave ovens. Conversely, providing users with blind data (and assuming a population steeped less in science than hearsay) could increase their paranoia when low-level field leakage from common appliances is visualized. Clearly, people need to be educated in how to properly interpret this data. Regardless of one's belief on the health impact of background EM fields, visualizing the unseen in this way always leads to fascinating and playful exploration. All devices emit background signals (electrostatically, magnetically, acoustically, and optically) that are characteristic of particular devices and also sometimes indicate that device's mode of operation. Indeed, government contracts mandate that computers and displays used in highly classified work be kept in shielded rooms (SCIFs) to thwart espionage that monitors such background leakage fields [13].

In this paper we present a cost-effective implementation of a wearable sensor to detect and display the strength and other characteristics of ambient electromagnetic fields. One implementation pursued in our work is the detection of the capacitively-coupled electric field emanating from a laptop display. To our knowledge, nobody has successfully designed a wearable device that detects and characterizes frequencies radiated from devices like laptop LCD screens, for example, or other appliances around us. Embedding our device into a bracelet offers an immediate awareness of the electromagnetic fields that surround us and are beyond human perception, enabling an extra sense similar to that possessed by electric fish [2]. We are researching the exploitation of such common background signals, such as near-field EM emission, optical modulation, and other invisible or intrinsic characteristics of the local environment in general to assist localization in smart systems.

Related Work

The public at large has long been concerned that exposure to radio frequency and generic electromagnetic sources are the cause of adverse health effects. Physicists Robert K. Adair [1] and Bob Park [16] explain that weak environmental fields at frequencies ranging from electrostatics through microwave cannot affect biology on the cell level, as the corresponding photons don't have enough energy to break a molecular bond. Only large electric fields have consequences that can lead to immediate injury or death, e.g. by electrocution or heating (and magnetic fields have even less effect). Although the public has been made aware of many medical studies indicating negative effects of electric fields, e.g., reports indicating an increase in leukemia for children living near power lines [5] and studies reporting an increased risk for brain tumors from the use of cell phones [11], the most careful studies have found no significant results to support a causal role for electromagnetic fields in causing cancer [12,16]. Nonetheless, some segments of society still consider the results of epidemiological studies on mobile phones, transmission towers, power lines, and other sources of EMI to be inconclusive. Accordingly, manufacturers of telephone handsets and commercial electronics, for example, remain interested in measuring the long-term integrated dose that is received from exposure to low-level EM fields. At present, no broadly accepted methodology for the assessment of long-term exposure from diverse EM sources has been developed.

Difficulties include high spatial and temporal variability of ambient electromagnetic fields together with their wide frequency span, as well as the fast change in the nature of common background signals due to rapid evolution of wireless communication technologies. At the moment there is no reliable method available to assess medium-term EM exposure [14].

Such popular fear of electromagnetic fields (EMF) has inspired artists in creating a dialog between their pieces and electric devices' users. Some have explored means to protect themselves from EMF exposure, mostly by creating a placebo effect. Zoe Papadopoulou knits copper filaments in her cosies to electrically ground them, hoping to provide some shielding from the EMF emitted by her devices. Through the process of production of the "cosies", the knitter feels empowerment and control. Dunne and Raby created underwear to psychologically protect the intimate parts of the body from EMF [6]. Naturally, such protection tricks work as a placebo effect, and do not provide any information on the EMF – they represent cultural fears. On the other hand, some artists have explored the playful side of exposing ambient signals – for example, Haruki Nishijima runs around with a "butterfly net" antenna to "catch" and archive broadband RF background, and Toshio Iwai sonified modulation in common background lighting using a portable device made by connecting an amplified photodiode to a speaker in his 2001 installation called "Photon." Commercial EMF detectors generally respond to low frequencies in the range of 50 to 1000 Hz [8], as they are built to show ambient low frequencies mainly emitted from power lines. Common EMF detectors are not contextualized and their interpretation and display is often unclear. They do not filter specific frequency bands and only show an integrated level between 50 to 1000hz. Such devices do not allow understanding of a specific emitted EMF. Semiconductor Films directed the *Magnetic Movie* at the Silver Space Science Laboratory. This movie graphically presents reconstructed surrounding electric fields in the environment [18]. It uses 3D composing with sound-controlled CGI to make magnetic fields visible. It is a literal visualization of how "invisible" magnetic fields could appear. Without a context, e.g. interacting with the equipment people usually use, the fields remain abstract and seem to be widespread. In our work, we propose that wearable devices could offer an instantaneous awareness about surrounding emanations and signals that are "invisible" within the context of use of everyday objects. Even though many designers have explored wearable EMF displays, we implemented an electric field sensor that is low-cost, this to democratize this EMF reading.

Design

We designed a wearable device, i.e. a bracelet, that responds to the non-perceived EMF that surrounds us that lies beyond human perception.

Circuit design

The bracelet contains an electrode antenna made from copper fabric and simple electronics that capacitively pick up the frequencies emitted from a laptop LCD screen. The user wears the bracelet and is coupled to the circuit's ground via the bracelet's inner electrode. The present design uses a high-impedance pickup electrode (actively shielded [3] from the body) on the outside of the bracelet. The circuit's front-end high-pass filter is designed to accept frequencies ranging from 50 kHz up to the 3Mhz-level rolloff of the amplifiers (lower frequencies can be accommodated by dropping the high-pass cutoff frequency). A peak detector extracts the resulting envelope, and the detected signal goes through two stages of amplification, providing a net gain of 55 dB. This envelope drives an LED that provides qualitative visual feedback on the local electric field intensity, changing brightness with field strength. The circuit board is sewed and connected to the bracelet (see Fig. 1).

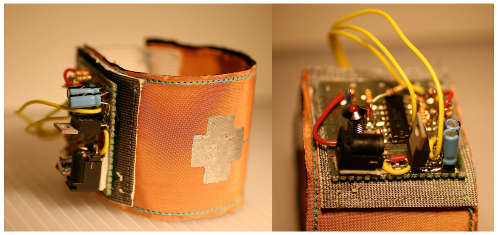

figure 1: The prototype circuit on the EMF detector bracelet.

Data from the bracelet can be retrieved and analyzed by a computer for more detailed visualization (through a custom designed software application) in addition to the immediate analog LED feedback on the device.

Results
Our first results were measured with an oscilloscope. The bracelet picks up frequencies above 50 kHz, such as radiated from a typical LCD laptop screen. We noticed that, as expected, the further away the bracelet is from the LCD laptop screen, the smaller the signals on the oscilloscope became. With our current antenna we can detect induced LCD signals up to 14 inches away from the laptop display (see figure 2a and 2b) – more range is easily possible with more amplification and a more sensitive front end.

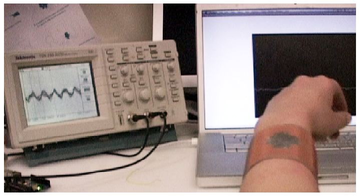

figure 2a: The bracelet is located at 14 inches away from the display – the oscilloscope shows the front-end output.

figure 2b: The bracelet is located at 1 inch away from the display.

In the second test, we embedded all electronics within the bracelet itself, exclusively using floating battery power, grounding only to the body, and only displaying a progressively illuminated LED to give us feedback on the level of signals in our passband. The circuit is still quite responsive - the LED progressively turns on starting at 12 inches from the LCD screen, achieving full brightness at a 1-inch proximity (see Figure 4).

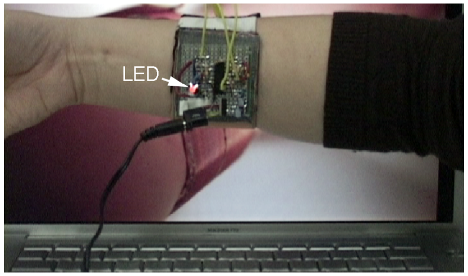

figure 4: The battery-powered bracelet is at 1 inch away from the screen, where the feedback LED is fully illuminated.

Discussion and Future Work
We are exploring a set of wearable devices and ambient objects that sense "invisible" information that surrounds us for adding context and localization in smart systems. These signals can also be analyzed to

identify particular devices, or infer the mode in which they are operating, (or also potentially decode a specific message that can be sent to the bracelet via a near-field artifact from a particular pattern on the screen or from a particular loop of code creating an explicit near-field emanation that leaks off a computer or other circuit board in the vein of "Tempest for Eliza" [15] which uses EMF produced by CRTs to send music to an AM radio), while the amplitude of these signals also indicates the proximity of the bracelet to the emanating device. Our prototype can easily be augmented with an embedded computer mounted as in a watch, and more detailed characterizations of the local background signals can be shown with an inexpensive display (pick-up artifacts from these components can be suppressed by the driven shield). Also, features extracted from these signals can be broadcast wirelessly (or used onboard) to help constrain a location-tracking system (by matching with the expected near-field and ambient "scent" present in particular locations). In the future, we would like to design a bracelet that can notify the user of relevant information derived from the perceived signals and hence offer an awareness beyond the human sensorial envelope.

More sensitivity can be attained with an improved front end, e.g., incorporating a transimpedance amplifier instead of a high-impedance buffer. Sensing across a wider frequency range (which can be analyzed in discrete bands to extract more features) can open this sensor up to emanations from other sources. For serious EMF monitoring applications, our device needs to be properly calibrated. Devices leak modulated signals into local environments via other channels as well, which can also be easily sensed in a compact wearable device to provide more data for visualization or context-extraction applications. AC magnetic fields can be sensed via compact 3-axis solid state or coil-based pickups [9], and common electric lighting sources also often exhibit particular modulation characteristics that can be detected with simple photodiodes (modulated light has been successfully exploited for indoor location systems [4,7,10]) – likewise, background acoustic and ultrasound signals can also be sensed and used.

As public debate on possible health effects of EMF rages on, many people have expressed interest in gauging the EM leakage from consumer devices. "Materializing" invisible emanations through data visualization, and supporting that information with rational guidelines on exposure (e.g., IEEE/ANSI C95.1) could be a helpful antidote for people stricken with irrational fear of EM exposure. Also, users could compare not only the EMF emitted from their computer, but also their entire set of electronic devices such as their television or artificial light. Visualization of EMF and comparing specific EMF sources is key for localization and context support as well as general EMF awareness, and will be explored in our future work.

Conclusion

We presented a cost-effective wearable sensor that detects the electromagnetic field of a laptop display. The closer the user wearing the bracelet is to the laptop display, the brighter the embedded feedback LED on the bracelet becomes. A bracelet of this sort can offer an immediate awareness of ambient electromagnetic fields that surround us, beyond human perception. Our future work will explore how we can exploit local electric and magnetic fields, modulated light, and generic RF signatures, extracting features from ambient background signals to provide an electronic "scent" of particular places or devices, adding context or helping localization in smart systems.

References

1. Adair, R. K.: http://spot.colorado.edu/~naglej/adair_and_emwaves.pdf
2. Bastian, J. (1994). Electrosensory Organisms. *Physics Today*, Vol. 47, No. 2, pp. 30-37.

3. Baxter, L. K. (1997). *Capacitive Sensors - Design and Applications,* IEEE Press.

4. Cheok, A.D. and Li, Y. (2008). Ubiquitous interaction with positioning and navigation using a novel light sensor-based information transmission system. *Personal and Ubiquitous Computing*, Vol. 12, 2008, pp. 445-458.

5. Draper, G., Vincent, T., Kroll, M. E. and Swanson, J. (2005). Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. *British Medical Journal*, June 05.

6. Dunne, A. and Raby, F. (2001). *Placebo*. 20c Study Gallery, Victoria & Albert Museum.

7. Eisenberg, A. (2001). Transforming a Fluorescent Glare Into a Guiding Light. *New York Times*, Oct. 11th 2001.

8. Electromagnetic Field Meter: http://www.emfmeter.com.au/index.html

9. Fraden, J. (2004). *Handbook of Modern Sensors*, Third Edition. Springer Verlag, Berlin.

10. Golding, A.R. and Lesh, N. (1999). "Indoor Navigation Using a Diverse Set of Cheap, Wearable Sensors," in Proc. of the IEEE *Third International Symposium on Wearable Computers* (ISWC 1999), pp. 29-36.

11. Hardell L, Mild KH, Carlberg M, Söderqvist F. (2006). Tumour risk associated with use of cellular telephones or cordless desktop telephones. *World Journal of Surgical Oncology*. 11;4:74.

12. Hepworth, S. J., Feltbower, R. G., Parslow, R. C. and McKinney, P. A. (2005). Childhood cancer and power lines: Results do not support causal role for electromagnetic fields. *British Medical Journal*, Sept 05.

13. Kuhn, M. G. and Anderson, R. J. 1998. Soft Tempest: Hidden Data Transmission Using Electromagnetic Emanations. In Proceedings of the Second international Workshop on information Hiding (April 14 - 17, 1998). D. Aucsmith, Ed. Lecture Notes In Computer Science, vol. 1525. Springer-Verlag, London, 124-142.

14. Neubauer, G., Feychting, M., Hamnerius, Y., Kheifets, L., Kuster, N., Ruiz, I., Schüz, J., Uberbacher, R., Wiart, J., and Roosli, M. (2007). Feasibility of future epidemiological studies on possible health effects of mobile phone base stations. *Bioelectromagnetics 2007*; Vol: 28 (3): 224-230.

15. Thiele, E. (2001). Tempest for Eliza. http://www.erikyyy.de/tempest/