

The HandWave Bluetooth Skin Conductance Sensor

Marc Strauss¹, Carson Reynolds¹, Stephen Hughes², Kyoung Park³,
Gary McDarby², and Rosalind W. Picard¹

¹ MIT Media Laboratory, 20 Ames Street, Cambridge, Massachusetts, 02139 USA
{mstrauss, carsonr, picard}@media.mit.edu

² Media Lab Europe, Sugar House Lane, Bellevue, Dublin 8, Ireland
{Stephen.Hughes, Gary.McDarby}@mle.ie

³ Digital Media Lab, 517-10 Dogok-Dong, Gangnam-gu, Seoul, Korea
park@icu.ac.kr

Abstract. HandWave is a small, wireless, networked skin conductance sensor for affective computing applications. It is used to detect information related to emotional, cognitive, and physical arousal of mobile users. Many existing affective computing systems make use of sensors that are inflexible and often physically attached to supporting computers. In contrast, HandWave allows an additional degree of flexibility by providing ad-hoc wireless networking capabilities to a wide variety of Bluetooth devices as well as adaptive biosignal amplification. As a consequence, HandWave is used in a variety of affective computing applications such as games, tutoring systems, experimental data collection, and augmented journaling. This paper describes the novel design attributes of this handheld sensor, its development, and various form factors. Future work includes an extension of this approach to other biometric signals of interest to affective computing researchers.

Author Keywords: Sensors, Affective Computing, Electrodermal Activity (EDA), Skin Conductance, Emotion Recognition, Wearable Computing, Bluetooth, Wireless Sensing.

ACM Classification Keywords: I.2.9.j Sensors B.4.3.h [Wireless systems]; H.5.2 [Information Interfaces and Presentation]: User Interfaces - theory and methods

1 Untethered Affect

Much of the work on ubiquitous and perceptual computing has focused on ways in which individuals can interact with computers in less constrained contexts than typing on a keyboard at a fixed desk. Indeed, affective computing ("computing that relates to, arises from, or deliberately influences emotion" [1]) is motivated in part by the potential for more human-like and natural communication with computers. Ironically, many current affective computing prototypes require that users be tethered in an unnatural, and often cumbersome, manner. The HandWave device provides an ex-

ample of a noticeably more flexible approach to sensing for affect, viewed from the standpoint of both users and application developers.

1.1 Affect Sensing

An affect sensor is a device that receives an input signal and processes it in order to detect some evidence of emotions. There are many techniques and modalities used to detect affect: physiological sensors, facial expression recognition, speech prosody recognition, and pressure sensors [2] have all been applied to the problem. Affect sensors are often coupled with algorithms that are specifically designed to distinguish and classify patterns associated with emotional states [3]. Among physiological signals, electrodermal activity [4], respiration, eletrokardiogram (EKG), and eyeblink rates have already been investigated by psychophysiology researchers.

1.2 Existing Electrodermal Activity Devices

A variety of devices and circuit designs already exist for detecting electrodermal activity. Three of the designs discussed below require that the user be cabled to a host computer. The last design, which uses Bluetooth, is similar to the HandWave, but is proprietary and closed.

ProComp. Biofeedback data acquisition devices have been used by a number of researchers to capture physiological data for affective computing applications. In addition to skin conductance, the ProComp series from Thought Technology Ltd. [7] is capable of capturing eight other channels that can be configured to collect "EEG, EKG, RMS EMG, ... heart rate, blood volume pulse, respiration, goniometry, force, and voltage input." The device communicates to a host computer using a fiber-optic cable, requiring the user to be tethered.

BioPac. The BioPac MP [8] is a modular system for collecting a variety of physiological signals for research or educational purposes. The system provides a data-acquisition board that can be connected to a host computer by USB or Ethernet cable. A variety of amplifier modules can be purchased for a wide variety of physiological signals including skin conductance.

Galvactivator. The affective computing group at the MIT Media Lab developed "a glove-like wearable device that senses the wearer's skin conductivity and maps its values to a bright LED display" [9]. The galvactivator device also provides a data port from which an analog to digital converter can sample. The sensor is comfortable, but requires that the wearer be cabled to a host computer to transmit EDA data.

Brainquiry. As a maker of "neurofeedback, biofeedback and psychophysiological measuring equipment," Brainquiry [10] sells a compact galvanic skin response sensor which uses Bluetooth to communicate with a host computer. However, little information is provided by the manufacturer about the proprietary design of the biofeedback amplifier.

2 Electrodermal Response

When one becomes mentally, emotionally, or physically aroused, a response is triggered in one's skin. Known as the electrodermal activity (EDA), this response can be used as an indicator of one's level of excitement or relaxation. This phenomenon is known as the sympathetic response, and is commonly referred to as "Fight or Flight." During excitation, in accordance with the sympathetic response, sweat glands in the skin fill with sweat, a weak electrolyte and good conductor. This results in many low-resistance parallel pathways, thereby increasing the conductivity of the skin [5].

EDA consists of two components: tonic and phasic [4]. The tonic component is a low frequency baseline conductivity level, which can oscillate over the course of days. The phasic component rides on top of the tonic component, is of higher frequency, and generally increases when a person is aroused. Problematically, each person has a different tonic conductivity, so in order to infer the arousal level of the subject, the relative changes in EDA must be analyzed over a period of time. Furthermore, skin conductance (measured in units of siemens; formerly mhos) depends on the skin path length between the two electrodes contacts, even for subjects with identical skin conductivity (measured in units of siemens/meter). It is for these reasons that it is crucial to analyze the temporal variations of the EDA signal.

3 HardWare

The core of the HandWave consists of two sandwiched printed circuit boards, one containing amplification circuitry, and one containing the Bluetooth module. The amplifier board provides the power connections and the terminal for the pair of electrodes. The device resides within an injection molded polypropylene housing, which includes an external power switch and electrode connection port.

We have designed the HandWave electronics and periphery in order to facilitate ease of use. For such a technology to become widespread, universality is essential. We decided to use Bluetooth technology and a standard battery size in order to increase the universality of the HandWave. These features allow the HandWave to be an off-the-shelf device, equipped for maximum operation with minimal support.

3.1 Amplifier Board

The amplification circuitry resident on the HandWave is centered around a PIC 16LF88 microcontroller. The PIC collects the EDA data, communicates with the processor embedded in the Bluetooth module, and controls the gain of the amplification circuitry. The analog-to-digital converter on the PIC is used to gather the EDA data. During operation, if the EDA signal approaches the limit of the ADC range, the PIC will adjust the amplification gain accordingly. The HandWave uses this adjustable gain to initially center and continually adjust the gain mode in order to increase EDA data resolution.

The signal amplification on the HandWave has two stages, implemented on a dual-package operational amplifier. The first stage of amplification uses a 0.5 Volt

reference to maintain a constant voltage across the skin. In accordance with an inverting amplifier configuration, the voltage gain of this stage is controlled by a resistance ratio. One of these resistances is provided by the subject's skin, as measured between a pair of electrodes. The other is subject to alteration by an analog switch, controlled by the PIC, which provides four different gain modes by switching different resistors into the circuit. The schematic for this first amplification stage is shown in Figure 1. The second amplification stage is used to invert, scale, and shift the EDA signal in order to match the PIC ADC usable voltage range.

The HandWave can measure skin conductance levels between 0 and 40 microsiemens (μS). The four gain modes have ranges of 0-5, 4-10, 8-20, and 16-40 μS . The gain mode information is transferred in parallel with ADC readings so the receiving computer can reconstruct the absolute measured skin conductance level.

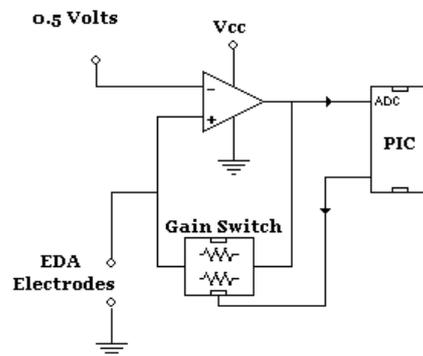


Fig. 1. First EDA signal amplification stage. The PIC can adjust the gain if the signal approaches the limit of the ADC range. Four gain modes are implemented in this way

The ADC on the PIC has 10-bit resolution. In order to detect EDA up to 20 Hz in frequency and attenuate signal noise to a level less than that which would alter the least significant bit, the PIC ADC samples at 1280 Hz. The PIC software averages every 32 samples, and the averages are sent over the wireless link at a rate of 40 Hz. In actuality, skin conductivity need not be measured at frequencies exceeding 5 Hz [11]. In the final prototype, the EDA signal resolution and sampling speed are high enough that minute changes in skin conductance from individual deep breaths are detected by the HandWave, as shown in Figure 2:

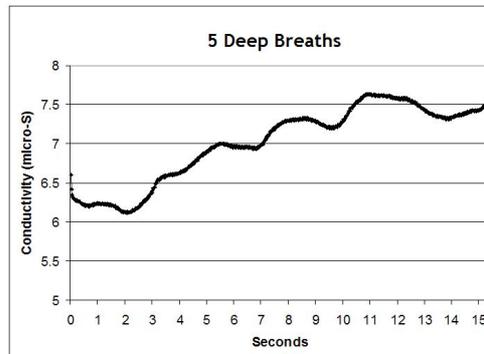


Fig. 2. EDA signal from the HandWave during deep breathing. The breaths can be seen in the fluctuations of the signal, and confirmed through comparison with the time axis

Many design considerations were combined in order to reduce the size of the HandWave. The geometry of the circuit boards, as well as their dense component arrangement significantly reduces the size of the device. The interface for in-circuit PIC programming consists of solder pads on the surface of the amplification board. Spring-loaded probes in a custom jig make electrical contact with these pads during programming. These design factors help to make the HandWave smaller and thereby less obtrusive to the wearer. The top of the amplifier board is shown in Figure 3:

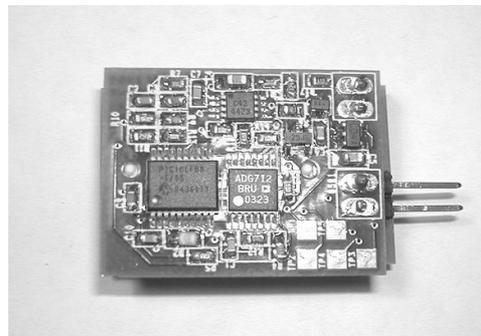


Fig. 3. HandWave amplification board. The size of the board was reduced by densely arranging the surface-mount components and utilizing solder pads for in-circuit programming

3.2 Bluetooth Board

The Bluetooth transceiver used for the HandWave is a Mitsumi WML-C20A module. This module is integrated with an antenna and a processor with 512 kB of flash ROM. During normal operation, the module streams the EDA output received from the PIC over the wireless link to a nearby Bluetooth-equipped computer. Being a class-1 module, the WML-C20A is specified to be able to maintain connections at up to 100 meters. The Bluetooth module can also send information received over the wireless link to the PIC, resulting in bi-directional data transfer capabilities.

3.3 Power and electrodes

The HandWave can be powered by any voltage source between 3.3 and 16 Volts. The device has been measured to draw approximately 70 mA of current during normal operation. The majority of the current is drawn by the Bluetooth module, which is specified to consume up to 150 mA.

Medical-grade electrodes are used in conjunction with conductive gel to provide a reliable electrical connection to the subject's skin. We have used Ag/AgCl electrodes placed either on two adjacent fingers or on opposite sides of the palm. These configurations both provide skin path lengths on the order of four inches.

3.4 Housing

The original form factor for the HandWave was a wristwatch. This allows a sturdy, adjustable fixation to the wrist, in close proximity to the hand where the electrodes are placed. However, the power consumption of the device necessitated replacement of the coin cell batteries after two hours of operation.

We next tested the HandWave in a handheld orb, with only electrodes and a power switch exposed. The orb allowed the use of a larger battery, which only had to be replaced occasionally. However, we found that the subject, while holding the orb, was able to significantly increase his EDA reading by squeezing the orb, thereby improving the fidelity of the electrode connection. These motion artifacts, compounded with the inconvenience of accessing the embedded device for maintenance, prompted the design and manufacture of a dedicated housing for the HandWave sensor.

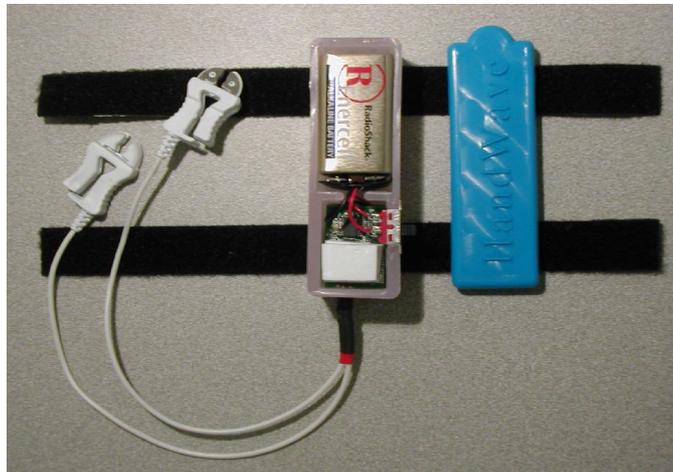


Fig. 8. The HandWave, replete with housing, battery, wrist straps, and electrode leads.

The most recent revision of the HandWave housing is shown in Figure 4. It is injection-molded out of polypropylene, and includes one cavity for the HandWave circuit boards, one cavity for a 9V battery, and one cavity for a power switch. There is also a single port on the side of the housing for connecting the electrodes to the am-

plifier board. The housing can be mounted on the wrist with Velcro straps or clips. The lid attaches to the housing body by means of a snap fit, and the power switch, circuit boards, and battery are press-fit into their respective cavities. The 9V battery provides power for approximately 10 hours of operation, and the press/snap fit assembly allows easy access to the interior elements. Finally, the electrodes are not situated on the housing itself, which prevents the wearer from inducing significant motion artifacts in the EDA signal.

4 Applications

The HandWave device is currently being used in a variety of different applications. This is due in part to the ease with which the device can be integrated into existing systems: the use of Bluetooth technology gives the HandWave universal connectivity, and the standard battery size and easy-access housing make it user-friendly. This allows the HandWave to transmit EDA data to preexisting computers, PDAs, mobile phones, or any other device which is equipped with a Bluetooth transceiver.

Big Gulp. A virtual environment that simulates underwater exploration in a shallow coral reef and along an undersea cliff. The environment is designed to support children engaged in inquiry-based science learning activities. We have developed a visualization of user attention maps in Big Gulp using a HandWave sensor. By stimulating users with startle events, we determined the location and intensity of user attention throughout the environment. Head direction readings reveal the areas of longest dwell time within the virtual world. The degree of attention level at particular regions is measured through EDA and represented by rendered air bubbles. The size of the bubbles represents the amplitude of changes in skin conductance.

Learning Companion. A relational agent that supports different meta-cognitive strategies to help students overcome frustration [12]. The system makes use of a large number of sensors: facial expression recognition, pressure-sensitive mouse and chair, and skin conductance as measured by a HandWave. Information from these sensors is merged to achieve affective mirroring: the agent subtly mimics the user's various aspects of the user's affective expressions.

Collective Calm. A multiplayer biofeedback video game that teaches players how to relax within a competitive environment while learning to cooperate as part of a team. The game is based around a virtual 'tug of war' competition between two teams in which each player gains individual strength by relaxing, and thereby decreasing his or her skin conductance. The team that collectively relaxes the most wins the game. HandWaves are used to measure each of the four players' EDA in real time.

5 Conclusions

We have described a wearable wireless skin conductance sensor, HandWave, and applications. The HandWave's small, unobtrusive form factor and use of wireless data transfer provide an additional degree of flexibility when compared to tethered skin conductance sensors. The use of Bluetooth technology and a standard battery size allows for portability and quick system integration. Future possibilities for the HandWave include creation of similar EKG, pulse rate, respiration, and other biosignal amplifiers for use with Bluetooth wireless data transfer. Furthermore, EDA sensors can be installed in existing handheld devices such as cellular phones, which already possess wireless capabilities.

References

- [1] Picard R.W. (1997). *Affective Computing* (MIT Press, Cambridge, MA)
- [2] Reynolds, C. (2001). The sensing and measurement of frustration with computers. Master's Thesis. Massachusetts Institute of Technology, Cambridge, MA.
- [3] Qi, Y. and Picard, R.W. (2002). Context-sensitive Bayesian Classifiers and Application to Mouse Pressure Pattern Classification, in *Proceedings of International Conference on Pattern Recognition*, August 2002, Quebec City, Canada.
- [4] Boucsein, W. (1992). *Electrodermal Activity*, Plenum Series in Behavioral Psychophysiology and Medicine, Plenum Press.
- [6] Malmivuo, J. Plonsey, R. "Bioelectromagnetism." *The Electrodermal Response*. Oxford University Press: New York. 1995.
- [7] Thought Technology Ltd. (2005). *Biofeedback Equipment: ProComp Infinity Hardware*. <http://www.thoughttechnology.com/procomp.htm>
- [8] BioPac Systems, Inc. (2005). *MP System Features*. http://www.biopac.com/mp100_features.htm
- [9] Picard, R. W. and Scheirer, J. (2001). The Galvactivator: A Glove that Senses and Communicates Skin Conductivity. *Proceedings 9th Int. Conf. on HCI*, 2001, New Orleans, USA, 2001.
- [10] Brainquiry, BV. (2005). *PET-GSR Wireless*. <http://www.brainquiry.nl/shop.php?pld=24>
- [11] Geddes L.A., Baker L.E. (1989). *Principles of Applied Biomedical Instrumentation*, 3rd ed., John Wiley, New York, N.Y.
- [12] Burleson, W. and R. W. Picard (2004). *Affective Agents: Sustaining Motivation to Learn Through Failure and a State of Stuck*. Social and Emotional Intelligence in Learning Environments Workshop In conjunction with the 7th International Conference on Intelligent Tutoring Systems, Maceio - Alagoas, Brasil, August 31st, 2004.