Physiological User Interfaces

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ABSTRACT
Physiological sensing offers a unique opportunity for constant, private, effortless interaction between man and machine. Physiological sensors have been used to study health, emotion and activity for decades and now modern sensors and mobile computing devices make it possible to record, analyze and respond to changes in physiological signals in real time mobile situations. This paper presents an overview of some research projects that demonstrate how physiological signals including GSR, EMG, EKG and respiration can be used as an alternative user interface, especially in new areas of computing such as mobile and ubiquitous control of consumer appliances.

KEYWORDS
Physiological, affective, wearable, computing, emotion, detection, startle, galvanic skin response, signal, sensor

INTRODUCTION

Physiological signals offer a new and different method for interacting with computers. The signals are constant, involuntary and do not require the user's attention to generate. These signals can be monitored, analyzed and interpreted by mobile or wearable devices or by systems embedded in office workstations or vehicles. Physiology conveys information about the user that is not captured by standard interaction through keyboard and mouse. This information includes signals relating to the user's activity level, health and emotional state.

This paper presents an overview of research projects that demonstrate how physiological signals can be used as alternative user interface. The system used for collecting the signals is introduced first, then three scenarios for using a physiological user interface are presented: a method for guiding music selection; an algorithm for automatic control of a digital camera and a system for detecting driver stress. The speed and accuracy of these algorithms are not sufficient to guarantee safety in automation applications such as the control of steering and braking in automobiles. However, current levels of performance can be used to automate less dangerous environmental variables such as music selection, lighting levels, phone call screening and taking pictures.

In the future, the physiological interface has even greater possibility as a method for detecting affective states. The final section of the paper presents an experiment where eight emotion states were recognized through physiological signals. This experiment was conducted in a controlled office environment using a pre-determined set of emotions that were intentionally expressed, however as sensors and algorithms for detecting emotion in physiology become more advanced, this type of interface could be used to detect emotion anytime, anywhere and respond to user preferences.

MEASURING PHYSIOLOGICAL RESPONSES

Physiological signals offer a new source of information about the user. These signals require special sensors to detect and can not be obtained from traditional interaction methods. Ideally we will find sensors that are as convenient to use and as inexpensive as a keyboard or mouse. One towards this goal is finding accurate, robust sensors that do not inconvenience the user. Many traditional measurements of physiology require constant skin contact with the sensor and give an even clearer signal when the skin is cleaned in preparation and a contact gel is applied.

Some ideas for physiological interfaces are based in the idea of embedding sensors into clothing, accessories [11] or peripherals [1] where sensors make contact with the user without disrupting the normal flow of the interaction. Constant contact can be problematic for sensors embedded in objects such as mice or steering wheels since a person might break contact with these objects to either shift their position or to switch tasks. Loss of contact can also be a problem for sensors embedded clothing and accessories when the sensors are not glued to the skin, since many actions can cause the sensors to slip with respect to the skin's surface such. Pressure variations from actions such as typing, grasping or walking also introduce artifacts in some sensors. For electrode based sensors, pressure at the point of contact of the sensor increases the measured conductivity, effecting GSR, electro-myograph (EMG) and electrocardiograph (EKG) readings. For other measurements, such as blood volume pulse (BVP) sensors pressure effects the physical phenomena being measured, in this case by compressing the blood vessels. Non-contact sensors would be the ideal solution, but they do not currently exist for many physiological signals and are not as available or accurate as standard sensors.

FIGURE 1. Components of the wearable system, clockwise from top: wireless modem, digital camera, wearable computer, sensor monitoring unit, EMG, BVP, GSR, RESP (coiled) PalmPilot interface, battery

To obtain the best signal, the experiments presented here used a set of standard physiological sensors with the appropriate gels and attachments to the skin. Often the sensors could be worn under the user's clothing to avoid further inconvenience or social discomfort.

WEARABLE APPLICATIONS

A wearable system with a physiological interface was created for several experiments. The physiological interface for this system consisted of several sensors including: a galvanic skin response (GSR) sensor for measuring skin conductivity; a blood volume pressure (BVP) sensor for measuring changes in capillary blood flow; an electro-myograph (EMG) for measuring muscle tension and a respiration sensor (RESP) for measuring changes in chest cavity expansion [9]. Additionally, the system had a PDA for input and output, a digital camera for recording pictures and an audio system for listening to music. The palm pilot interface was used to monitor the sensors, to make annotations to the data and to manually control the digital camera and music selection programs [6].

These devices were attached to a wearable computer that was capable of storing a day of physiological data or transmitting the data back to a server using either a wireless modem or wireless Ethernet. The components of this system are shown in Figure 1.

Experiments were conducted to measure the physiological changes caused by various physical activities such as sitting, walking, jogging, transitioning from sitting to standing and sudden events such as coughing and sneezing [9].

To monitor daily activities the camera stored thumbnail snapshots from the digital camera at the rate of one every two seconds. At the end of the day, a record of the wearer's day could be seen as a series of pictures that could be matched to his or her physiological signals [2]. From these records, changes in physiology could be found that corresponded to activities such as climbing up stairs, typing, transitioning from sitting to walking and muscle tension changing as the user switched the satchel from one shoulder to the other [3].

GUIDING MUSIC SELECTION

As an example of an environmental appliance that could be controlled through physiology, an algorithm was created for automatic music selection based on galvanic skin response. Music selection can be a complex process involving many factors of a person's overall personality and preferences as well as their momentary mood changes.

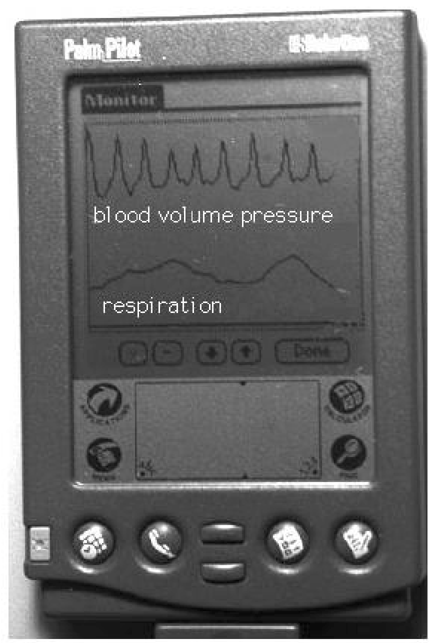

FIGURE 2. An example of the PalmPilot interface in monitoring mode. BVP and RESP signals are shown.

In this application, an algorithm was created to select music based on the overall change in a person's skin conductivity over the first two minutes of a song. To account for the different musical preferences, the user created lists of songs he or she enjoyed and put them into two play lists. Playlist "A" consisted of songs the user found more relaxing and Playlist "B" consisted of songs the user found more stimulating.

The GSR signal was captured by two sensors on the user's fingers, as shown in Figure 3, digitized and then sent to the wearable computer for analysis. If there was an overall increase in the person's GSR, the computer selected the next song from Playlist A and conversely, if there was an overall decrease in GSR the algorithm selected a song from Playlist B [6]. A pseudo-random number generator was used to select the next song from within the play list. Initially, an attempt was made to order the play lists according to the degree of relaxation or stimulation they represented to the user and to map the change in the GSR to an appropriate change in the song list using the relaxation-stimulation ratings. Unfortunately, this mapping proved to be difficult and resulted in the same songs being played too frequently, which the users did not find enjoyable.

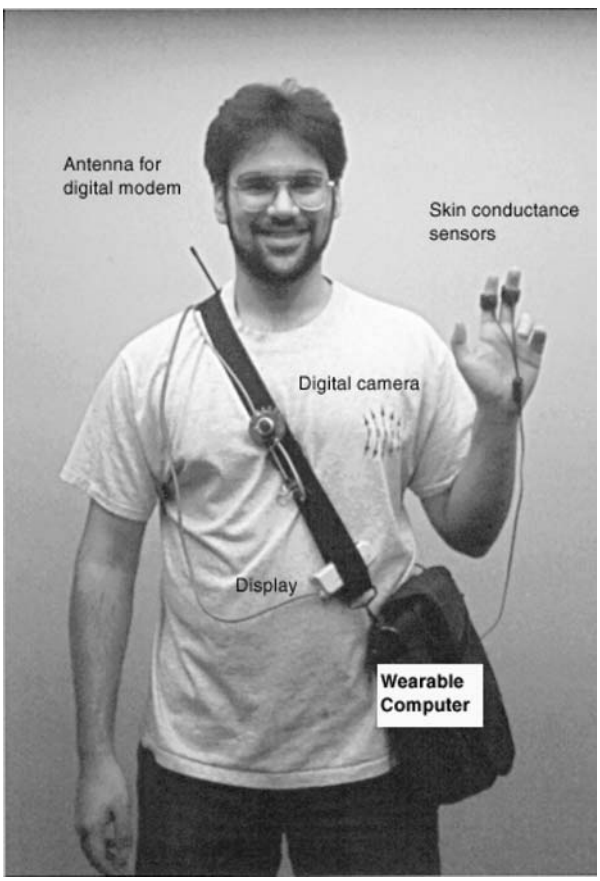

FIGURE 3. The wearable system showing placement of digital camera and skin conductance sensors for music selection and StartleCam applications. This configuration shows a PrivateEye used for a display.

A more sophisticated system could learn a user's play list preferences and use an algorithm pick similar songs automatically from a more diverse collection. Also, instead of simply switching between two play lists, patterns of features could be recognized from the physiology of the person listening and different patterns of music could be played in response.

STARTLE ACTIVATED CAMERA

A different type of application is one where the user wishes the computer to have automatic control of a specific device in a certain situation. An example of this type of application is a startle activated camera that is programmed to take pictures and send them over the internet when the interface detects a sudden and significant skin conductance orienting response. Such sudden responses could indicate that the user has encountered something that is jeopardizing their safety such as an assailant or a misstep and sudden fall.

This application uses the wearable system shown in Figure 3 to detect GSR from the hand, perform analysis using a wearable computer and based on the result of the analysis decides whether or not to transmit the series of pictures it has been collecting using a digital camera. Three examples of the startle pattern the algorithm detects are shown in

Figure 4.

The algorithm takes the raw GSR signal, applies a smoothing filter to it, then calculated the signal's first derivative (slope). If the algorithm detects a first derivative that exceeds a pre-set threshold (this can be tailored to the

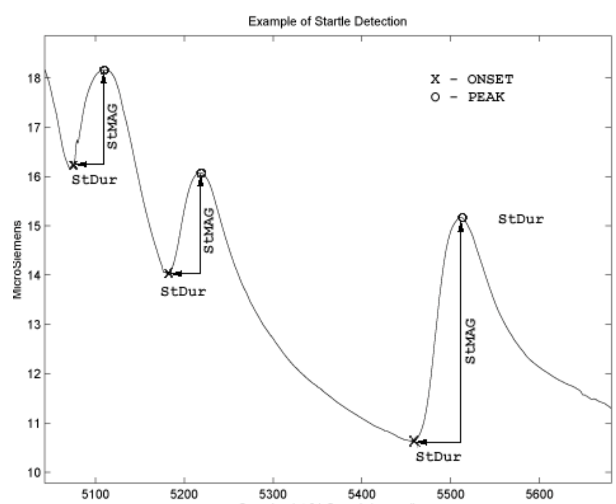

FIGURE 4. Three startle patterns with the magnitude (StMAG) and duration (StDUR) measurements shown as calculated by the detection algorithm.

individual user) a startle was triggered.

This detection method was used for real time applications because it introduced the least amount of latency into the system. However, this method does not fully characterize the response since the threshold crossing does not represent the beginning of the response and algorithm the peak of the response often occurs several seconds later. In later experiments when response characteristics were considered more important than latency, the algorithm was modified to return to the original smoothed signal to find the beginning and peak of the startle, using the trigger point as a reference. These points were found using a search for the nearest local minimum and maximum to the trigger point. In practice this was found to be more reliable than attempting to find the zero points of the second derivative of the sampled signal. The resulting magnitude and duration measurements for each response are shown in Figure 4.

The physiological interface presents several challenges for this application. One challenge is finding the best threshold to use to trigger the detection of a "startle." Many factors should be considered for this decision including the propensity of the individual to produce orienting responses, the normal size of these responses and the motivation behind activating the camera. For a safety application, the threshold should be set high so that only the most extreme reactions will trigger reaction. However, for an application where the user only wants to store local image reminders of things that have caught their attention a lower threshold can be used. A second challenge is that many physical activities also trigger orienting responses, such as a light going on or a moving object being sighted. Some physical events such as sneezing or coughing often cause very large responses that could easily be mistaken for a great alarm.

A third challenge the inherent latency of the GSR orienting response. The physiological reaction that causes the response shown in Figure 4 begins only after the person's body has had time to react to the stimulating event and his or her sweat glands begin to fill. The delay between the event and the response can be up to three seconds long. Therefore, the application can not simply take pictures when the startle is detected, but rather the system needs to constantly record pictures and send or download those pictures associated with the moments just before the response was detected. To compensate, the system was designed to maintain a rotating buffer of up to ten digital images in which the least recent image was overwritten by a new image every 0.5 to 2 seconds. The number of images in the buffer and the rate of image acquisition could be varied depending on personal preference and the degree of detail needed for the application. The entire buffer of images showing a series of snapshots describing the past several seconds is saved or transmitted whenever a startle event is detected by the threshold trigger [5].

DETECTING DRIVER STRESS

Another useful place for a physiological interface is in an automobile where distracting from the driver's attention is most undesirable. Cell phones and Internet appliances might be fine to use under easy driving conditions, but might annoy or distract the driver under more stressful conditions. A physiological computing system in a car [6] could measure the drivers' reactions under different circumstances and model the driver's state as being in a certain stress category. If the driver were in a low stress situation, the computer could allow full bandwidth interaction with appliances and then cut back on features as the drivers stress category increased, for example switching from video to audio navigation interfaces or preventing cell phone calls.

To identify stress levels through physiology an experiment was conducted to measure drivers' physiology as they drove through three different road conditions. An algorithm was developed that used features from GSR, EKG, RESP and EMG signals to identify the three major stress conditions with results as high as 96% accuracy [3]. The automobile is a particularly good place to measure use a physiological interface because the user's motion is naturally constrained by the driving task and any motion that does occur can be more easily monitored using cameras, pressure sensors or information from the car's computer regarding steering, accelerating and braking.

FIGURE 5. A screen from the digital video record of the drive showing, clockwise from the top left: the view from the steering wheel camera; the view from the rear camera; the physiological signals and the wide angle view from the dashboard.

DISCRIMINATING EMOTION STATES

Since the time of William James it has been speculated that physiology can be used to detect unique emotional signatures. If emotional patterns can be reliably detected through a physiological interface then an entirely new mode of interaction with computers becomes possible [8]. Computers could learn automatically what we like and dislike and which features of interaction please or frustrate us, and hopefully the computer will be able to adapt to our preferred mode of interaction or make intelligent suggestions for our schedules. Measuring the physiological changes associated with emotion is difficult in an ambulatory environment where physical actions can overwhelm any other signal, but in a stationary setting, such as when the user is before a desktop machine these changes are more readily apparent.

To this end, an experiment was conducted to record the physiological signals associated with eight emotions from a subject who tried to genuinely feel these emotions each day for the thirty days of the experiment. Based on the data from this single subject, computer recognition algorithms were created to try to automatically recognize each of the eight emotion states. These analyses found that it was possible for the computer to discriminate the eight categories of emotion from physiological categories of data at accuracy rates comparable to those reported for human emotion recognition by humans [4][10]. These results support the idea that we may one day be able to let the computer know how we are feeling about it.

CONCLUSIONS

Physiology offers a different kind of interface to computers and a different kind of human computer interaction. Through a physiological interface we are not communicating considered thoughts represented by numbers or language, but rather a series of reactions that we ourselves do not entirely control. The message that these reactions convey may not be what we intend and may not be precise enough to warrant using them for critical applications, but for certain consumer oriented non-critical applications these messages may be the ideally effortless user interface.

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AUTHOR'S NOTE

Many of these references are available for download from the Media Lab's Technical Reports website at the address: http://www.media.mit.edu/publications/

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