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Wearable Sensor Platform and Mobile Application for Use in Cognitive Behavioral Therapy for Drug Addiction and PTSD

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***Abstract* — We present a wearable sensor platform designed for monitoring and studying autonomic nervous system (ANS) activity for the purpose of mental health treatment and interventions. The mobile sensor system consists of a sensor band worn on the ankle that continuously monitors electrodermal activity (EDA), 3-axis acceleration, and temperature. A custom-designed ECG heart monitor worn on the chest is also used as an optional part of the system. The EDA signal from the ankle bands provides a measure sympathetic nervous system activity and used to detect arousal events. The optional ECG data can be used to improve the sensor classification algorithm and provide a measure of emotional "valence." Both types of sensor bands contain a Bluetooth radio that enables communication with the patient's mobile phone. When a specific arousal event is detected, the phone automatically presents therapeutic and empathetic messages to the patient in the tradition of Cognitive Behavioral Therapy (CBT). As an example of clinical use, we describe how the system is currently being used in an ongoing study for patients with drug-addiction and post-traumatic stress disorder (PTSD).**

***Index Terms* — mobile health, cognitive behavioral therapy, wearable sensors, drug addiction, PTSD.**

I. Introduction and Motivation

A. The Need for Mobile Monitoring and Interventions

Mental health and behavioral disorders are generally difficult to treat and difficult to monitor. Common examples include a variety of addictions (drugs, gambling, food, etc.) as well as anxiety disorders or depression. Psychiatric interventions traditionally occur in the clinic, through scheduled doctor visits. Unfortunately, due to social stigma, financial means, or inconvenience, patients often discontinue the doctor visits before the treatment is complete. In addition, prescribing medication may not be appropriate or desired by the patient.

In addition to limited opportunity for treatment, there is also a lack of information about a patient's mood or behavior outside of the clinic. Mobile technologies thus represent an opportunity to be able to monitor patient mental health in between doctor visits and also provide an additional therapeutic channel to the patient.

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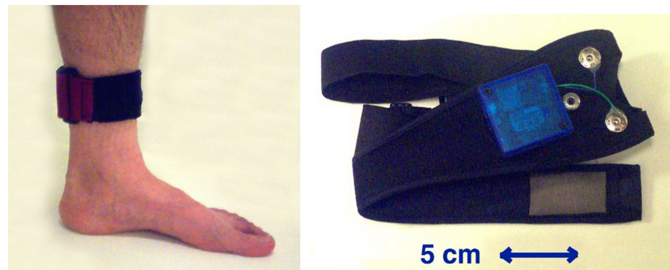

Fig. 1. (left) Photograph of wireless ankle sensor band; (right) photograph of wireless ECG sensor mounted on chest strap.

B. Monitoring Mood, Emotion, and Behavior

Unlike pathologies that have obvious clinical symptoms (e.g. heart arrythmia, diebetes), common mental health ailments or disorders require the ability to monitor and recognize a patient's mood or behavior over time, which is an inherently challenging task for machines or computers.

In the context of mobile phones or PDA's, electronic patient questionnaires, otherwise known as Ecological Momentary Assessments (EMA) are generally used to ascertain a person's emotional state without the need for recall or patient diaries [1]. However, the EMA task in itself presents a cognitive load that can also affect the person's emotional state.

More recent work in the field of emotion has focused on electronic measurement of emotion by monitoring the Autonomic Nervous System (ANS) activity and using a simple two-dimensional model of emotion or mood with "arousal" and "valence" as its principle axes [2-4]. Of particular interest in the mental health context is the activation of the Sympathetic Nervous System (SNS), which is often associated with emotional stress and produces increased electrodermal activity, dilation of the bronchioles, discharge of adrenaline, inhibition of digestion, elevation in blood pressure, and increased heart rate. The Parasympathetic Nervous system (PNS) generally acts to increase the tone of smooth muscles and slow the heart rate.

Although the heart rate variability (HRV) and the ECG waveform itself (e.g. QT interval, stroke volume) can be

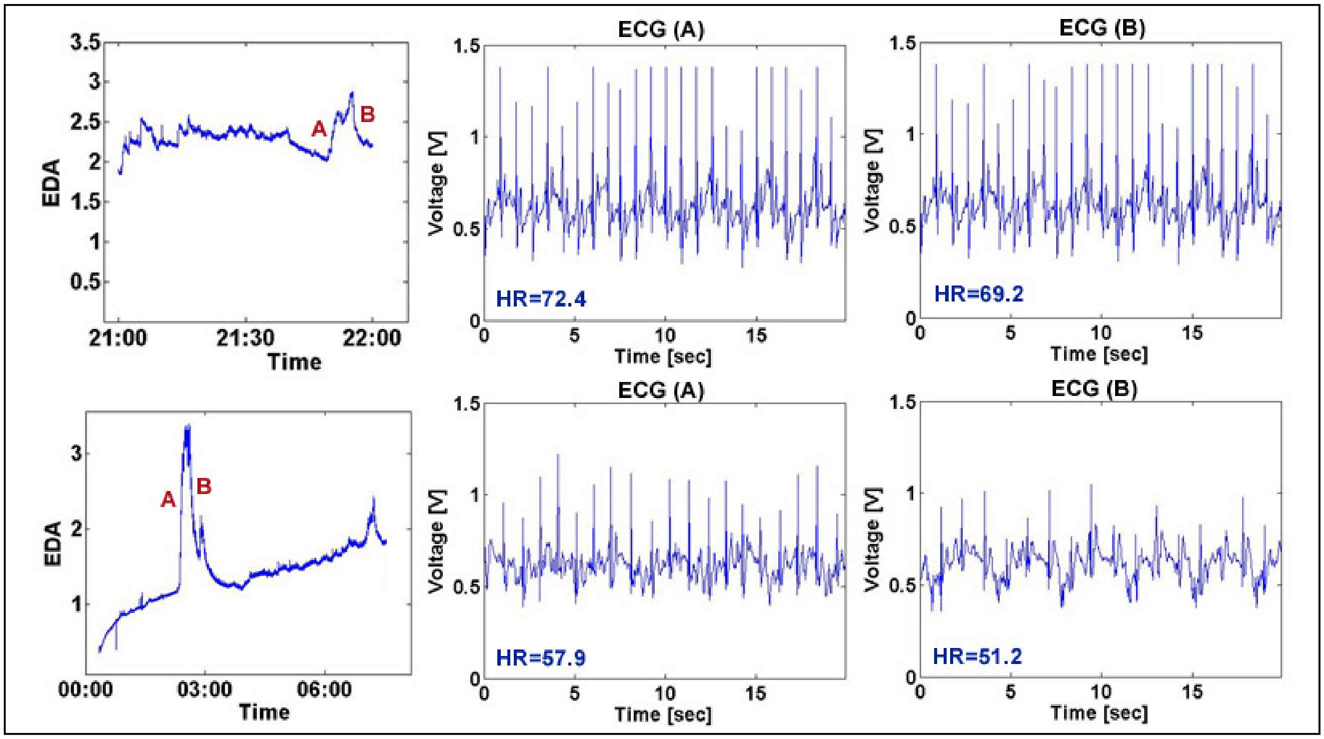

Fig. 2. Plots of EDA and ECG data simultaneously collected in the evening (top set) and during sleep (bottom set). For each set of plots, the left and right ECG plots are 20-second windows corresponding to points A and B in the EDA plot, respectively. Time axis on EDA plots is actual military time. A large EDA peak during sleep can be noted.

used as indicators of SNS activity or *arousal*, it is generally less desirable to use this technique in mobile health platforms due to practical limitations on the sampling rate, power consumption, and motion artifacts in the waveform data. Compared to ECG, the skin conductance or electrodermal activity (EDA) measured from the wrist or ankle (instead of fingers) has proven to be a more robust measure of arousal which does not require a high sampling rate [4]. If necessary, a measure of *valence* can be derived from the heart rate variability and power spectral analysis with increased low-frequency content being associated with negative valence.

C. The Opportunity for Therapeutic Interventions

Given the ability to measure a person's mood or stress with small wearable sensors, it then becomes relevant to consider how portable mobile technologies could be used for therapeutic purposes as well. [5] Recent advances in mobile phone processor speeds and open software development tools have made the phone a very attractive tool for use in mental health interventions. Mobile phones not only provide a live connection to a remote server for data collection, but they also provide a rich array of interface hardware with which to interact with the user.

Cognitive behavioral therapy (CBT) is a standard procedure for treating many mental health disorders such as addictions or anxiety and is readily adaptable to a mobile platform [6]. The therapy consists of techniques for self reflection as well as techniques for coping with episodes of craving or stress. Examples include relaxation techniques (e.g. breathing exercises) or imagery ("*Imagine yourself on a beach…").*

The use of CBT combined with physiological monitoring has only recently been demonstrated [7] making use of the decrease in heart rate variability (HRV) as a measure of patient stress. While this demonstration was successful, a particular challenge was the high degree of variability in the physiological responses from patients as well as the high degree of variability in the required patient therapeutic messaging. This need for individual customization is another key feature that we have addressed in the system design presented in this paper.

II. DESCRIPTION OF MOBILE PLATFORM

A. Wearable Sensor Bands

As shown in Fig. 1, the wearable sensors consist of a neoprene band that contains circuitry for measuring electrodermal activity (EDA), 3-axis motion, and temperature [4]. Although this device could be worn on the wrist, the patients in our focus group preferred the ankle for reasons of comfort as well as for privacy.

The sensor bands contain a low-power 8-bit microcontroller (Atmel XMega) with 12-bit ADC resolution for sampling the analog sensors, and a real-time clock that generates millisecond time-stamped data packets. A low-power Bluetooth radio was incorporated into the electronic module to enable communication directly with the mobile phone. The sampling rate can be dynamically controlled via the Bluetooth connection over a range of 0.1 Hz to 32 Hz. A 2 GB MicroSD card is also included in the band to provide local storage and caching of data, which is useful when the phone is not in radio range. The sensor band also contains a 500 mAh battery which provides 9 hours of continuous use at a sampling rate of 4Hz, but can be adjusted if longer battery life is desired.

B. Wearable ECG Heart Monitor

Although commercial Bluetooth ECG heart monitors exist, we decided to build our own ECG monitor so that we could precisely control the sampling rate and filtering, and also use the same wireless data protocol that is employed in our other sensor bands. This enables the wireless ECG data to be seamlessly integrated with the data from other sensor bands into a single data collection point (e.g. mobile phone) using a common data format.

Shown in Fig. 1, the 2-lead ECG heart monitor is constructed around a TI INA322 differential amplifier circuit with two 6-pole elliptical notch filters to attenuate ambient noise pickup at 50 Hz and 60 Hz respectively. The ECG monitor also uses the Atmel Xmega low-power microcontroller with 12-bit ADC and a 2 GB SD card and Bluetooth module for data transmission and storage. A real-time clock with millisecond time stamps was also implemented. The ECG band contains a slightly bigger 750 mAhr rechargeable lithium battery. Although a sampling rate of 100 Hz or higher is generally desired, we chose 32 Hz in order to achieve 9 hours of battery life to match the battery life of the phone and other sensor bands.

Initial testing of the sensor bands was performed by wearing both ankle and chest bands simultaneously for eight hours during the day and eight hours during sleep, with the intervening time used for charging batteries. Sample data is shown in Fig. 2.

C. Mobile Phone Software

The mobile phone software was implemented using the Android OS and the JAVA SDK. Two separate phone models were used: the Nexus One phone, running Android 2.2 for use in the clinical data collection by the research staff, and a very small mobile phone (Motorola Flipout, running Android 2.1) was chosen for use as the dedicated CBT device to be carried by each patient.

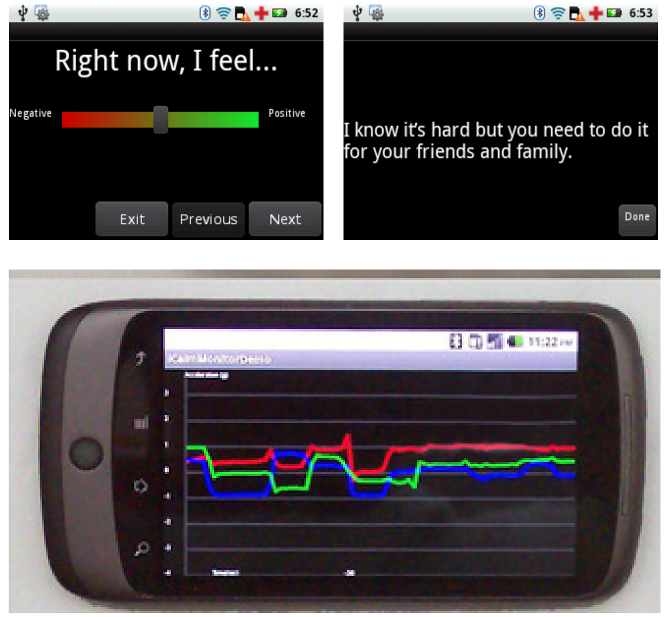

Fig. 3. (top) Photograph of phone screens showing sample EMA and CBT messages. (bottom) Photograph of live data plot from sensors during drug cue testing.

Two separate phone applications were created for use in the study. For the purpose of collecting training data in the drug cue testing lab, we created an application that is capable of recording live data from multiple Bluetooth sensor bands simultaneously and displaying live plots (Fig. 3 bottom). For the purpose of mobile CBT, a multi-threaded application was created that runs several services in the background and launches Android activities to display intervention messages and EMA surveys (Fig. 3 top). We implemented our program as a custom home screen activity, which launches automatically when the phone is powered on, and we disabled all other user buttons and controls so that the phone could not be used for any other purpose other than CBT.

D. Web Server and Database

A custom server JAVA application was created to support remote log-in and review of anonymous de-identified patient data and user settings. In addition to viewing patient sensor data and assessment results, a key feature of our system is the means to remotely update and adjust the CBT sensor algorithm parameters on each patient's phone. Patient data was stored on a remote Microsoft MS-SQL secure database server located in a high-security facility requiring VPN access.

III. Clinical Use of Mobile Platform

A. Study Description

The mobile CBT platform was developed as part of an ongoing study (NIH project 5RC1DA028428-02) with military veterans that are recovering from drug addiction and PTSD, which have emerged as significant risk factors for homelessness, family issues, and suicides. Twenty five patients ages 22-55 were recruited from the resident drug rehabilitation program at the local Veterans Administration Hospital. The study protocol consists of four data collection sessions in a controlled environment followed by 2 weeks of CBT using the mobile phone in the patient's natural environment.

B. Drug Cue Testing Lab

As part of the study protocol, several sessions are conducted with each patient in a controlled environment to record the patient's physiological baseline and also to test the patient's physiological reactivity to specific drug cues. (data from this phase will be published in a separate paper) For this experiment, the ankle bands and ECG heart monitor are both used to collect data.

C. EMA and CBT Interaction Design

For the mobile ambulatory phase of the project, only the ankle sensor bands are used (primarily for reasons of comfort and convenience). For CBT, three separate modes of patient interaction were created using the mobile phone:

1) Immediate Craving: If the patient is feeling an immediate drug craving, the patient can push this button to report the craving. The phone then proceeds to ask the patient several questions about the nature of the craving and end with a therapeutic and empathetic message.

2) Physiology-based Interaction: If the phone detects an unusual arousal event (defined by physiological signature customized to each specific patient), then the phone will alert the user and display a message "*How are things going?*" If the user answers "Fine," we handle this as a false positive and the system goes back to its quiet monitoring state. But if the patient answers "*Not so good*" then the phone proceeds to ask the patient several questions about mood and drug craving ending with a therapeutic and empathetic message. If the patient ignores the message, or cannot attend to the phone (e.g. busy or driving) then the message will automatically disappear after 30 seconds.

3) Random EMA Assessments: In order to validate the sensor classification algorithm and also collect additional subjective information, a standard EMA assessment is also presented to the patient at random time intervals, approximately 2 hours apart. At each occurrence, a message is first displayed "*May I ask you a few questions?*" If the patient ignores this message, or responds "*Not right now,*" then the EMA will be reattempted after 15 minutes. Otherwise, the EMA will proceed with several questions about the person's mood, current activity, and drug cravings, ending with a therapeutic and empathetic message.

In our current study, patients tested thus far have exhibited at least some degree of reactivity (EDA and heart rate response) when presented with PTSD and drug cues in the lab. Preliminary patient feedback on the mobile CBT has been positive. This work is ongoing.

IV. Results and Summary

We have built a wearable sensor system that is capable of monitoring a patient's physiology and is able to deliver therapeutic interventions via the patient's mobile phone based on specific autonomic nervous system activity. In addition to the use of physiology to initiate the therapeutic interaction, another key innovative feature of the system is the ability to individually customize the sensor classification algorithm and the therapeutic messaging for each patient through the use of a centralized web server.

While the application of wearable sensors to mental health is still at a very early stage, we feel that systems such as these represent a significant milestone in the treatment of mental health issues and can be readily adopted for use as an adjunct to traditional clinical therapy in the future.

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