

FEEL

A System For Acquisition, Processing and Visualization of Biophysiological Signals and Contextual Information

by

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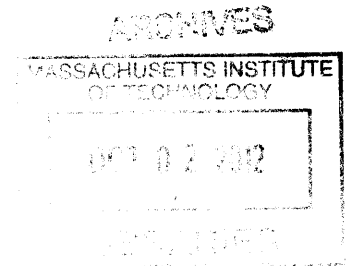
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Abstract

If we are to learn the effects of the environment and our day-to-day actions, and choices on our physiology, we must develop systems that will label biophysiological sensor data with contextual information. In this thesis I first present an architecture and implementation of FEEL: a system for the acquisition, processing and visualization of biophysiological signals and contextual information. The system comprises a mobile client application (FMC) and a backend server. The mobile client collects contextual information: phone call details, email reading details, calendar entries, and user location at a fixed interval that is transmitted to the backend server. The backend server stores the contextual information and biophysiological signal data that is uploaded by the user, processes the information and provides a novel interface for viewing the combined data. Next, I present the results of a 10-day user study in which users wore Electrodermal Activity (EDA) wrist sensors that measured their autonomic arousal levels. These users were requested to upload the sensor data and annotate it at the end of the day at first, and then after two days. One group of users had access to both the signal and the full contextual information collected by the mobile phone and the other group could only access the bio physiological signal. At the end of the study the users were asked to fill in a System Usability Scale (SUS) questionnaire, a user experience survey and a Toronto-Alexithymia (TAS-20) questionnaire. My results show that the FEEL system enables the users to annotate bio-physiological signals at a greater effectiveness than the current state of the art. Finally, I showed that there is a correlation between a person's ability to determine their own arousal level and their score on the Toronto-alexithymia test: the less alexithymic they were, the better their correlation between the EDA and their self-reported arousal.

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Chapter 1

Introduction

1.1 The problem of missing context

State of the art technology has made it possible to monitor various physiological signals for prolonged periods. Using wearable sensors, individuals can be monitored, sensor data can be collected and stored in digital format, transmitted to remote locations, and analyzed at later times. Such a technology opens the door for a multitude of exciting and innovative applications. We could learn the effects of the environment and our day-to-day actions, and choices on our physiology. How do the number of sleep hours affect our activity levels during the following day. How do the times we schedule our meals impact our performance? How does physical activity affect our quality of sleep? Do such choices have an impact on chronic conditions?

Physiological signals are only part of the information required to answer such questions. It is necessary to label these signals with contextual information. Context is defined as: “the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood and assessed” [1]. Ideally, one would want to have access to full contextual information alongside with the sensor data. This may include location, activity, nutrition, social interactions, etc. The contextual information can be acquired by one of 2 methods:

1. Self-report – the individual being monitored maintains a diary and logs the required information.
2. Observation – an entity (human or machine) observes the monitored individual and maintains a journal of the individuals’ actions.

The first method has one major drawback. It requires the monitored individual to actively report the necessary information. This by itself is intrusive and causes a disruption in the persons’ routines.

Another limitation is that the individual may not be aware of all the minute events and their significance as they occur. A seemingly insignificant event may have a notable impact on our physiology. An event's true significance may only be revealed during the analysis of the physiological data along side with the contextual information.

The second method may seem attractive at first. Enable a machine to record the entire context: video, audio, and all other information. But this technique it is not without limitations.

This approach will result in massive amounts of raw data that will require the classification of the data for finding pertinent data points, for instance, classifying whether someone appearing in a video recording is considered a social interaction or just a person passing by. It is necessary to filter all of the contextual information in order to determine the "relevant context".

A third approach is a combination of the two first approaches. Human input can trigger the automated collection of contextual data during significant events. Triggers could be automated based on changes in variables such as location, voice, or human action such as receiving a phone call. Triggers can also be manual such as instructing a machine to record context at a relevant time. This approach avoids the collection and processing of "irrelevant context".

1.2 Motivation - The 'Crit Day' study

Public speaking is often associated with high levels of stress and anxiety. Many individuals fear being in the spotlight, being the center of attention, and the possibility of standing on stage and forgetting what they meant to say. Additional elements that may add to the anxiety are the possibility of being asked questions that they are not prepared to answer. We set out to characterize the skin conductance changes related to public speaking. Would it be possible to find a correlation between speakers perceived stress levels and their physiological response? Were the levels of stress highest before, during or after a talk? Were the physiological responses of individuals that perceived themselves as very stressed higher than the ones of those that perceived themselves as calm?

Each year, the MIT Media Lab organizes an event in which second year master's students present their thesis proposal to all of faculty, students, and researchers. Each proposal is evaluated in terms of

depth, originality, and contribution. At the beginning of this seminar, the students are told of the importance of their 'Crit Day' performance that will be a factor that weighs heavily in their Ph.D. application. Naturally, this adds significant levels of stress to the students who realize that this speaking event may determine the future of their academic career.

We decided that 'Crit Day' was a valuable opportunity to measure the physiological effects of public speaking.

We recruited 11 graduate students, 8 males and 3 females, who were designated to present on 'Crit Day'. During the study we collected Skin conductance, skin temperature, and 3-axis accelerometer – we used the Affectiva Q™ wristband sensor. Each participant received a pair of sensors, one for each wrist, so we could collect bi-lateral data. The participants were asked to wear the sensors for 72 hours starting on the morning of the day before their presentation. In addition, we interviewed each participant a few days after the end of the measurements. During those interviews, we asked the participants to describe their experiences during the 72 hours. We asked them to note any unexpected events or events that caused them a great deal of anxiety or emotional strain.

We recorded the exact times of presentation and Q&A sessions after the presentation for each participant. We found that we had all the necessary information to perform analysis on the EDA signals recorded on those times. However, on the other recordings we were missing the contextual information to determine what had happened. On some of the EDA peaks we could determine that there was a high level of activity that could account for the increase in EDA but for others we lacked the information needed to make an inference. We were missing the contextual information. In order to obtain that data we asked the participants to maintain journals of what had happened to them during the three days of the study. We held exit interviews with the participants at the conclusion of the study. We found that most of the participants did not have a good memory as to what had happened during the times when there was a rise in the EDA signal. Most participants consulted their journals, and if the events were not transcribed in the journal, they used other means such as phone logs and calendars to determine what they did at the time.

1.3 FEEL – Frequent EDA and Event Logging

The motivation for creating FEEL was to see if a system could be created that would capture the users' context in an unobtrusive manner by using a mobile phone and then combine that context with a physiological signal to provide insights into the changes of the signal. One of the drawbacks of this approach is that the mobile phone does not have all the sensors and logic to determine the full context of the user. It is capable of obtaining partial context only. It is aware of whether or not a user is having a phone call, if the user is at a certain location, if the user is browsing the web or using an app or reading an email, but it is not aware of other occurrences that are more minute. The resolution of context obtainable by a mobile phone is such that it provides a high level picture of what the user was doing. We may still need the user to label and annotate the signal to achieve a higher resolution. At times the high level picture will provide sufficient information as to whether or not a specific event contributed to the change of the biological signal.

The idea was that by providing users with the biophysiological signal combined with the contextual information, they would be able to better recall which event occurred during that time. Even if we could not record the specific context because the phone lacks the sensors and logic to decode that context, we still have other events before and after that could serve as anchors or memory prosthetics for the user and enable him to gain insight into the data and annotate and label those events.

This idea was tested by setting up a study comparing two groups of users, one that could only access the biophysiological signal and the other that could access both the signal and contextual information acquired by their mobile phone. Both groups were required to label the signal in terms of their valence and arousal as well as rate the confidence of their ratings. If the system combining biophysiology with context works better than the one with biophysiology only, then we would find validation for our idea. Later in this thesis we describe the specific study and its component hypotheses.

The approach was to create a mobile application that runs un-obtrusively on the mobile phone as a service. The application is constantly recording contextual information. It is aware of changes in location, phone calls that the user is holding, calendar entries and meetings that appear on the calendar, and emails that the user is reading. Any one of those events will be recorded and can later

serve as a reference point for annotating the physiological sensor recording. The second element of the system is a web platform that combines the contextual information and physiological information and enables the user to view the contextual information overlaid on top of the physiological data in a user-friendly interface. The user can determine where he was or what he was doing and view the changes that occur in his physiology during those times.

The approach was to test the system out in the wild, in contrast with testing it in a laboratory setting where everything could be recorded and annotated. The goal was to see if it was possible to record the users in their everyday experiences and whether the system could determine the contextual information and provide the user with a tool that would assist them in annotating the data and also assist in providing short term insights from the data. The long term goal is to use the system with any type of bio-physiological sensors – not just EDA sensors, however the system was evaluated with EDA sensors because they are currently available commercially, are comfortable to wear, and have sufficient battery life to last for a full day of recording.

There are several contributions made by this thesis. The first is an architecture and implementation of a system for acquisition, processing and visualization of biophysiological signals and contextual information. The second is a user study that shows that a system that automatically gathers context is useful in physiological data recording and can provide a more superior experience than the current state of the art: maintaining a journal manually in combination with using additional tools to look at the sensor data alongside with the contextual information. Lastly, this thesis provides some insights regarding human's abilities to evaluate their own arousal levels.

In the next chapter I will describe the background information and related work done in fields related to this research, in experience sampling, automatic contextual detection and recording of EDA. Then, I will provide an overview of the system architecture and a detailed description of the FEEL mobile client, backend server, and web application.

Next, I will describe the experimental design and user evaluation, continuing with the results obtained from the user study, and finishing with a discussion and future work.

Chapter 2

Background and Related Work

The proliferation of wearable sensing systems has made it possible to continuously record various physiological signals for prolonged periods. Affectiva [2], Bodymedia [3], and others have created devices that collect a continuous stream of physiological data.

Other devices such as Fitbit [4], FuelBand [5], Pebble [6], and Up [7] gather information regarding user activity for later analysis and display on a PC or mobile phone.

The common denominator between these devices is that they collect physiological information, but lack contextual information. It is possible to analyze the data in order to detect trends such as: daily and monthly activity trends, physiological arousal trends, etc. However, it is very difficult to perform a causal analysis on this data in order to find the underlying reasons for differences and trends. For instance: inferring the reasons for an observed increase in the physiological arousal level would require additional information. In order to answer questions of this sort, it is necessary to determine contextual information. In this thesis, I explore the notion of a system that obtains contextual information from a mobile phone in combination with physiological data that is displayed in an intuitive interface.

2.1 Context Recognition using Mobile Devices

The notion of automatically acquiring context by using mobile phones is well known in the field of life-logging or reality data mining. This can be attributed to the fact that such phones are pervasive and personal [8]. Brown and Randell [9] discussed the idea of building a context sensitive phone and the various pitfalls that one may encounter in the process.

Iso et al. [10] showed that it was possible to extract personal context information by using a mobile phone equipped with specialized sensors. The authors exhibited extracting physical and environmental context as well as biological user context that may be used to infer emotional state.

Lee and Kwon [11] proposed an architecture of general wearable sensors for determining emotional context as well as an architecture for emotion based content services.

Kern et al. [12] showed that it was possible to determine activity context from accelerator readings, social context from audio and interruptability from a combination of these along with WLAN based location estimation. The authors showed that by using these techniques in an experimental evaluation they were able to achieve detection rates of 97.2% and 90.5% for social and personal interruptability, respectively. The goal of this study was to demonstrate the viability of a system that would automatically create real-world meta information that would ease the retrieval of live life recordings.

2.2 Context Aware Experience Sampling

In traditional experience sampling, the user is polled at random times and asked to report his emotional state as well as his current activity. This is an intrusive process that may affect the user's experience and therefore alter the reports.

In one study, Lawrence [13] showed how the cell phone and its sensors can be used to non-intrusively obtain many types of contextual data such as the location, body postures or activities. In a different work, Froehlich et al. [14] developed MyExperience, a system for capturing both objective and subjective in situ data on mobile computing activities. Various events such as device usage, location, or context can trigger the capture of the current user experience. The user experience can be either readings from sensors that are connected to the phone, or subjective user feedback (such as a survey). Although this method is less invasive than triggering the question at random times, the users will still need to devote some cognitive effort and mentally map their affect to an entry.

A less intrusive method to obtain the affective responses is via using an affective wearable device [15]. Picard and Liu [16][17] monitored stress levels of PDA users and provided a line of empathy while asking them to annotate their levels, a combination that resulted in reduced stress compared to a similar but non-empathetic annotation condition. The system supported collection of heart signal data, accelerometer, and pedometer information, as well as automatic labeling of location

information from context beacons and would poll the user to annotate his stress levels dependent on the context.

In a different study, Kang et al. [18] measured the levels of stress of cell phone users when using several services in order to create a personalized and more optimal service. Intille et al. [19] developed a system for context-aware experience sampling. Their system reduced the need for polling the user at random times, and enabled researchers to query the user only within a specific context (e.g. when a user is at a specific location). Raij et al. [20] designed and evaluated a smartphone based system that continuously collects and processes multi-modal measurements from wearable wireless sensors to infer in real-time whether the user wearing the sensors is stressed, and generates prompts for timely collection of self-reports, to record the experience of stress when it is fresh in the user's mind

Work has also been done in the field of automatic assessment of user affective state without the need for self-report. Picard et al. [21] developed a physiological signal-based emotion recognition system that used a facial muscle tension sensor, photoplethysmograph, electro-dermal activity (EDA) and a respiration sensor. K.H. Kim, Band and S.R. Kim [22] proposed a similar system that uses EDA, skin temperature and ECG sensors. Ertin et al. [23] developed a wearable wireless sensor suite that collects and processes cardiovascular, respiratory, and thermoregularity measurements on a smartphone in order to inform about the user's level of stress.

2.3 Electrodermal Activity

The concept of Electrodermal Activity has been recorded as early as the late 1800's by French neurologist Fe're' (1888) and Russian physiologist Tarchanoff (1889) independent of one another.

Fe're discovered that when introducing a direct current, the skin resistance decreased due to emotional or sensory stimuli. Tarchanoff found changes in skin potential following sensory stimulation, Imagination, cognitive load, and voluntary muscle contractions.

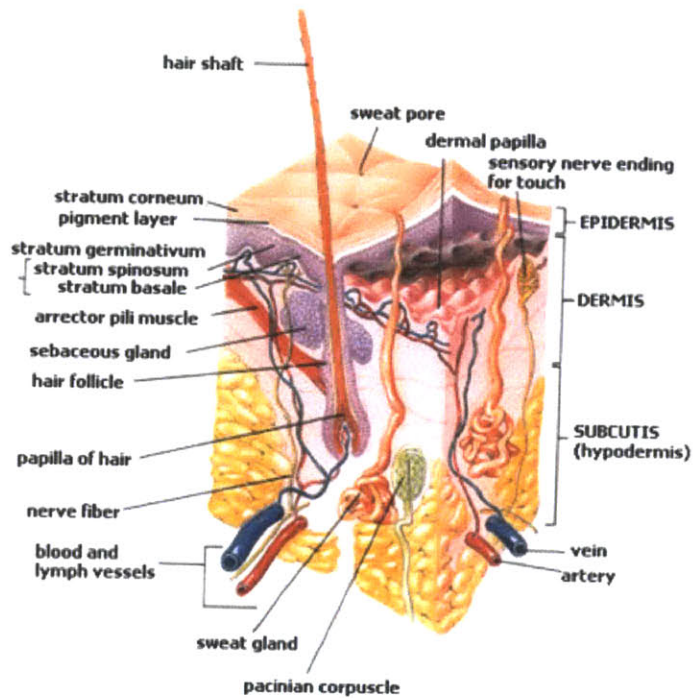


Figure 2.1 Anatomy of the human skin (taken from [24])

The Dermis layer, which lies beneath the Epidermis (Skin) contains Eccrine sweat glands, which have a coiled and tubed form. These glands discharge their secretions directly onto the surface of the skin and can be found only in primates. They are located in various regions of the body but they are highly dense (>250 glands/cm²) on the soles, palms, and scalp.

The primary function of the Eccrine sweat glands is to assist in the thermal regulation of the body. However, the secretion of sweat within the Eccrine glands is also affected by psychological state: Arousal, emotional state and stress all contribute to changes in secretion. Electrodermal activity can thus change with emotional load, cognitive load, or physical load.

When applying a constant voltage to the skin, it is possible to measure the current flow, which increases with increased skin conductance. This can be achieved by placing a resistor in series with the skin and measuring the voltage across the resistor, which is proportional to the skin resistance and thus inversely proportional to the skin conductance. For bi-polar recordings Fowles et al. [25] recommend to apply a voltage of 0.5 Volt.

The skin has an inner conductive layer and an outer layer that contains a barrier for water; therefore, it is less conductive. The sweat gland ducts break this barrier, and allow the electricity to flow through them. As more sweat is secreted the skin becomes more conductive.

Although there is still much to learn regarding the exact causes of EDA, there exists clinical evidence that points to some of its origins. According to Boucsein[26]: “In summary, the experimental as well as clinical evidence concerning the CNS elicitation of EDA points to the existence of two different origins above reticular level, which were already suggested by Edelberg (1972a): a limbic-hypothalamic source labeled EDA1, being thermoregulatory and also emotionally influenced, and a premotor-basal ganglia source labeled EDA2, eliciting electrodermal concomitants of the preparation of specific motor actions. In addition, there may be a reticular modulating system which mediates EDA changes that appear with variations of general arousal... The reticular modulating system is also likely to be responsible for inhibitory influences on EDA ..., which may be either ipsi- or contralateral. “

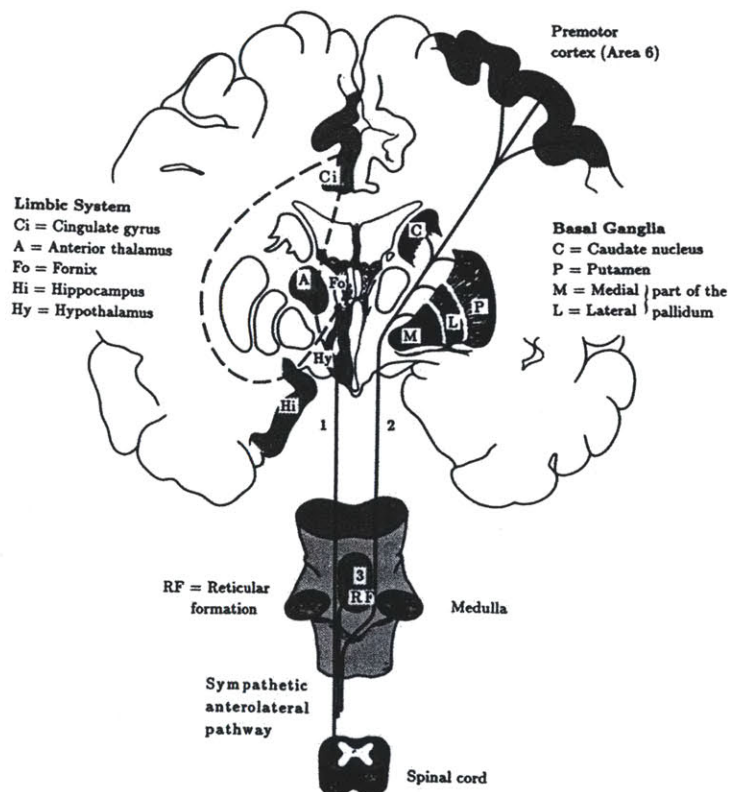


Figure 2.2 Central nervous system elicitation of EDA in humans (taken from [26])

Although not shown in the diagram above, the limbic structures are also involved in the elicitation of EDA. Mangina and Beuzeron-Mangina [27] found that when directly stimulating limbic structures there was strong ipsilateral control of the elicitation of bilateral EDA in humans. They discovered that when particularly electrically stimulating the amygdalae high SCRs were measured.

Historically EDA was used as a tool to assess arousal mainly in a laboratory setting. Fowles et al. [25] published recommendations for electrode placement sites and suggest to use the palmar sites whenever possible as there is a large body of literature that uses these sites. It is possible to use either the thenar and hypothenar eminences or the medial and distal phalanges of the fingers. If both hands are to perform some active task, recordings should be taken from the plantar surface of the feet.

However, in order to perform long term recordings, it is necessary to find a site that would enable the effective measurement of EDA:

1. Enable the user to maintain a daily schedule without disruption – placing electrodes on either the fingers or palms would be inconvenient. The measured signal would also be highly susceptible to noise introduced by movement and pressure artifacts [28]
2. Provide a high correlation with the EDA measured at the fingers, palms or soles

Poh et al. [29] showed that there was a strong correlation between EDA measured at the fingers and distal forearm during physical ($r = 0.78$) and emotional ($r = 0.72$) tasks. There was also a correlation during cognitive tasks ($r = 0.57$).

Van Dooren et al. [30] compared 16 different locations for measuring emotionally induced sweating. The authors found that EDA measured at the wrist was positively correlated with the EDA measured at the fingers as a result of emotional inducing stimuli.

These findings make an EDA sensor worn on the wrist a good alternative to sensors worn on the finger or palmar surface. In addition, wearing a sensor on the wrist is convenient and non intrusive as it does not interfere with manual activities such as working on a computer.

Fletcher et al. [31] showed that advances in battery technology and low power microelectronics have enabled the creation of wearable autonomic activity logging sensors that can provide non intrusive ambulatory measurement during day to day activities.

Chapter 3

System design and architecture

In a system that annotates bio-physiological data there are several necessary components. The first is the sensor, which will acquire the physiological data and store it in digital format. The second is a component that will acquire the contextual data and provide the annotations. The third component is the backend server, which processes, integrates and stores both the bio-physiological data and the contextual data. And lastly, the interface - a component that provides the user with a convenient interface for accessing the data. In the following sections, I will describe each of these elements in detail.

3.1 Physiological data acquisition

The FEEL system was designed to work with any physiological time series data. For the purpose of evaluating the system a sensor that would satisfy the following requirements was selected:

- Comfortable to wear for prolonged periods of time
- Extended battery life that would enable a day of operation without charging
- Simple operation that would enable unobtrusive data acquisition

The Q Sensor manufactured by Affectiva as seen in the images below complies with these criteria.



Figure 3.1 Affectiva Q Curve EDA sensor (left) and Q POD EDA sensor (right)

The Q sensor measures electro-dermal activity or changes in the skins' ability to conduct electricity. The changes are a direct result of the Autonomous Nervous System (ANS) [26] controlling the sweat glands in the sub dermal layer. As sweat is released from the glands to the skin surface, the skin conductance increases. The changes in the skin hydration may be the result of emotional changes, cognitive, physical load, sweating or thermo-regulation. The Q sensor can measure these minuscule changes and store them in digital format within the sensor for later retrieval. The sensor also records skin temperature and 3-axis accelerometer. A USB connector enables the user to connect the sensor to a computer and download the data.

3.2 Acquiring contextual data - Use the Mobile Phone as a Platform

Mobile technology is ubiquitous [8]. Over 87% of the world populations [32] currently own a mobile phone. Many people use their phone as a communication portal to the world. Voice calls, Emails, SMS's and IMs all provide a means for individuals to communicate. Mobile web browsers and applications enable the consumption of content anywhere. An embedded calendar allows people to schedule meetings with one another and social networks allow people to update one another on events that occur during their lives. The mobile phone is used as a tool to create and maintain social relationships.

In addition to enabling individuals to communicate with one another and access information anywhere, modern mobile phones have a multitude of sensors. Microphones, cameras, accelerometers, GPS, and similar all provide the means for applications to read the state of the state of its immediate environment.

These communication and sensing capabilities make the mobile phone an exceptional tool for determining context.

Finding the geographical context (where we are) - is done via GPS, and social context (who we are communicating with) is done via email, call logs and social networking applications, as well as blue-tooth proximity detection. In addition most smart phones today have accelerometers that can provide a measure of physical activity context - was I inactive or being physically active this morning. The modern mobile phone is very compact yet has sufficient processing power to execute very demanding applications and therefor is well suited for this type of project. And finally, the mobile phone is one of the indispensable objects that people carry with them [33] and as such is a good proxy for people's interaction with the environment.

3.3 The FEEL Mobile Client

The FEEL Mobile Client (FMC) is a Java Android application that I wrote, which runs as a background service on the user's mobile phone. Its main objective is capturing changes in the users context and sending them to the backend server for processing and storage. The FMC starts automatically when the phone is powered on and is very lightweight in terms of memory, processor and battery usage. It was decided to support Android because it is a widely deployed platform, has excellent developer support and enables easy access to all of the phone's content (calendar, emails) and sensors (GPS, accelerometers, Bluetooth) via a uniform API. In the future it will be possible to support IOS and Windows Mobile. The design principles leading the design of the FMC were:

1. Unobtrusiveness – this was probably the most significant principle. By definition, FEEL should sample the user's context without interrupting the user. An application that requires the user to actively perform actions is intrusive and may alter the very context that it is trying to measure.
2. Robustness – The primary goal of the FMC is data collection; therefore, it is imperative that the application maintains a persistent data store. If the user is in an area that does not have mobile coverage, the FMC should retain the data until connectivity is resumed.
3. Low battery use – short battery life would have a negative impact on the data collection. If the phone shuts down, there will be a gap in the data collection process. In addition, the user may not agree to use the application if it shortens the phone's battery life.
4. Low processor usage – the FMC should not affect any other of the applications running on the phone and should not block or delay any OS services.
5. Extendibility – novel mobile phones with new types of sensors are constantly introduced to the market. Supporting new types of sensors should have few consequences on the FMC architecture. The sensor monitors encapsulate the sensor specific data types and the communication layers need not be aware of those.
6. Portability – The FMC was designed to run on a variety of Android mobile phones. Because it is lightweight, it may run on older devices with slower processors and smaller memory sizes. Additionally, it does not utilize any device manufacture proprietary APIs but rather pure Android APIs.

The FMC is composed of the following modules:

Activity Monitors- these monitors are tailored to listen for occurrences of specific events or changes in the users context. A monitor may be of one of two types: event-triggered or periodic. An event-triggered monitor is asynchronous. It registers itself to receive notifications on the occurrences of events as they occur in real-time. For instance, the phone-call monitor will be activated every time an incoming phone call arrives or when the user initiates a new phone call (an off hook event). Periodic monitors are synchronous and are activated in fixed intervals, perform a set of actions and are then suspended until the next interval. The period is set to create a good balance between device battery life and event detection latency. An example for a periodic monitor is the location monitor. It is activated every 30 minutes and determines whether the current location reading has changed from the previous reading. After determining that an event took place, the activity monitors sends a message to the Event listener module.

The following Activity Monitors are currently supported:

Phone Call Monitor- the Phone Call Monitor is event triggered and supports the following events: incoming call start, incoming call end, outgoing call start, outgoing call end. The monitor also measures the duration of the conversation. At the end of the call, a message that includes the following fields is generated:

<i>Phone number</i>	<i>Start Time (UTC)</i>	<i>End Time (UTC)</i>	<i>Contact name</i>
---------------------	-------------------------	-----------------------	---------------------

Calendar Monitor- This is a periodic monitor that is activated every 30 minutes. It scans the users Google calendar and determines which calendar entries start in the upcoming hour and sends these as messages to the Event Listener. The message includes the following fields:

<i>Start Time (UTC)</i>	<i>End Time (UTC)</i>	<i>Title</i>	<i>Location</i>	<i>Attendees</i>	<i>Description</i>
-------------------------	-----------------------	--------------	-----------------	------------------	--------------------

Email Monitor- This is an event-triggered monitor that is triggered every time the user starts reading an email or finishes reading an email. Currently, only the K9mail [34] email client is supported. The K9mail client is an open source android email client that was modified in order to generate an event

each time a user selects an email for reading, and each time a user exits a mail reading view. The monitor measures when the event occurred and what was the duration of the reading. When the user finishes reading the email a message containing the following fields is sent to the Event listener:

<i>Email Sender</i>	<i>Email Sent Time</i>	<i>Email text</i>	<i>Email Recipients To</i>	<i>Email Recipients CC</i>	<i>View Start Time</i>	<i>View End Time</i>
-------------------------	----------------------------	-------------------	--------------------------------	--------------------------------	----------------------------	--------------------------

Location Monitor- This monitor is a periodic monitor that is activated every 30 minutes. It determines whether the current location is different then previously read location using GPS and WiFi. In case of a change, the following information is sent to the Event Listener:

<i>Time (UTC)</i>	<i>Current Location Latitude</i>	<i>Current Location Longitude</i>	<i>Location Method (GPS / WiFi)</i>
-------------------	--------------------------------------	---------------------------------------	---

Event Listener - the Event Listener provides the activity monitors with an interface for buffering events prior to their transmission to the FEEL backend server. The Event Listener stores the events in a queue located in the phone memory. The buffer is used to prevent cases where the ingress of even rates exceeds the egress of the transmission rate to the back-end server.

Event Transmitter- This module sends events to the backend server located in the cloud. The Event Transmitter is suspended and waits for messages in the message queue. It reads each event from the queue, formats a URL, and tries to initiate an HTTP connection with the backend server. When the connection succeeds, the Event Transmitter sends the event details encoded in an HTTP GET request. The event transmitter was designed with robustness in mind. There may be times when the connection to the backend server will fail; The backend server may be down for maintenance, the user may be located in an area with no network coverage, or at peak times the server may be momentarily inaccessible due to an overload by other requests. In order to support unexpected scenarios such as these, a retry mechanism was implemented.

In case the connection fails the transmitter will retry the transmission and repeat this process for three times. Finally, if the transmission fails after these retries the transmitter will suspend itself and retry the whole transmission process after 20 minutes in order to preserve battery life.

User Interface- the user interface module provides a user interface to the FMC. It enables the user to view the number of events currently stored in the internal queue waiting for transmission to the back end server as well as the time of the last connection to the server.

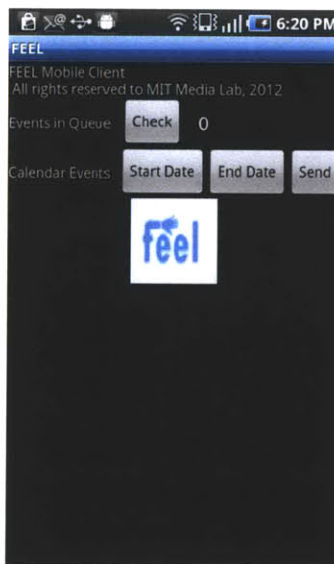


Figure 3.3 The FMC user interface

The FMC UI also enables manual initiation of the calendar monitor to run within a window of two dates. All calendar entries that appear within the configured window are sent to the backend server. This is useful in case the user added entries to the calendar retroactively. The monitor will only detect them in case they are in the future, and therefore it is necessary to initiate the calendar monitor manually using the interface.

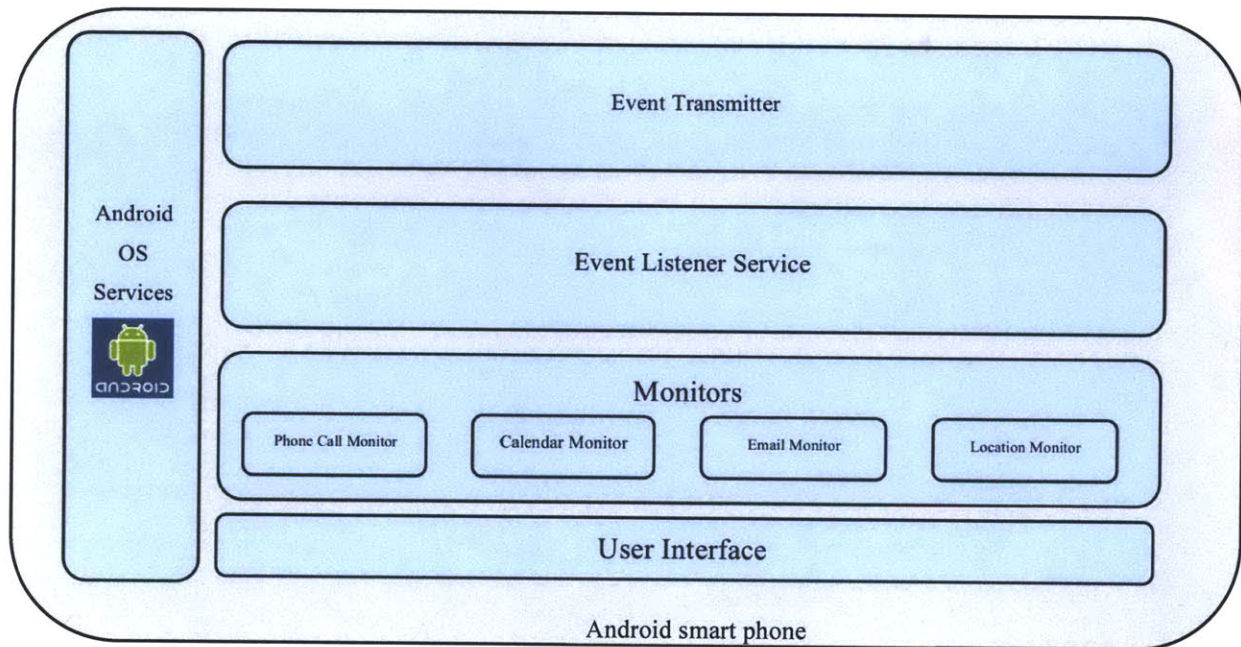


Figure 3.4 FMC high level block diagram



Figure 3.5 The FEEL logo

3.4 The FEEL Backend Server

The FEEL system was designed with cloud computing paradigms in mind. Cloud computing enables high availability and scalability, which are desirable qualities in a large data, computationally intensive application such as this. In addition, high availability is necessary because the events are sent in real-time to the server. This enables data processing in real-time and in the future will facilitate for the system to perform interventions.

Another key consideration made in the design of the server was to maintain separation between the database logic, the application logic, and the user interface and each of these should be fully self-contained. The Model-View-Controller (MVC) [35] design pattern was used:

1. **The Model:** the data structures representing the application's state. Namely this is the data base used to store user sensor data, profile data, and login session
2. **The View:** this element observes the model and generates output to the users. Namely, these are web pages and AJAX responses sent to the browser.
3. **The Controller:** the function of the controller is to translate the user input into operations that are then executed on the model.

By using MVC it is possible to extend the application and add additional functionality to specific elements with little or no modification to others. One could for instance change the layout of the web page without affecting the database or the application logic.

The server is composed of the following elements:

Web Server- The web server has a dual purpose – it is used both for receiving events from the FMC and for serving the user interface web pages. We will discuss the latter functionality in the user interface section.

Tornado 2.0 [36] is the web server that was selected for the system. It is open-source, lightweight, scalable, non-blocking and can handle thousands of simultaneous connections. Tornado is implemented entirely in Python and does not have any dependency on external modules. In the FEEL implementation Tornado is configured to run multiple instances in parallel to support concurrent

connections. Each instance runs in a separate process, and the processes are distributed evenly to run across multiple processors (or cores) on a single machine.

Core application- The feel core application manages the data and signal processing, data storage and data retrieval, and user session information.

The core application is written completely in Python an open source object-oriented programming language. Python was chosen because of its ease of use, maintainability, platform independence and the large number of available modules. An additional strength is the availability of NumPy [37] and SciPy [38] : open source packages for scientific computing with Python, rather than using a commercial data analysis product such as Matlab that provides comparable functionality.

Python version 2.7.1 was used along with Numpy version 1.5.1 and Scipy version 0.8.0

Other Python modules that were used:

md5 - Implements the interface to RSA's MD5 message digest algorithm

uuid – provides immutable Universally Unique Identifiers (UUIDs)

hashlib - Implements a common interface to many different secure hash and message digest algorithms.

Data Base Server- The database server stores the following:

- Physiological sensor data – EDA, skin temperature and accelerometer data. The sensor data is divided into segments of 30 minutes each for fast and flexible access to specific measurement times.
- Events and user context – phone call information, calendar entries, email reading and location information
- User self report data – event descriptions, valance, arousal and event recall clarity
- User profiles and session information – user email, phone number, encrypted password and current session

MySQL [38] the world's leading open source relational database was chosen as the system database. Its major benefits are high performance, high reliability, ease of use and widely available support from the open source community.

Server Hardware and Operating System– The FEEL system is currently running on a 64bit Quad core AMD Opteron(tm) Processor 6180 SE. The cores are running at 2.5Ghz. The system has 2Ghz of RAM. The Operating system is Ubuntu Linux 11.04, kernel version 2.6.38-13

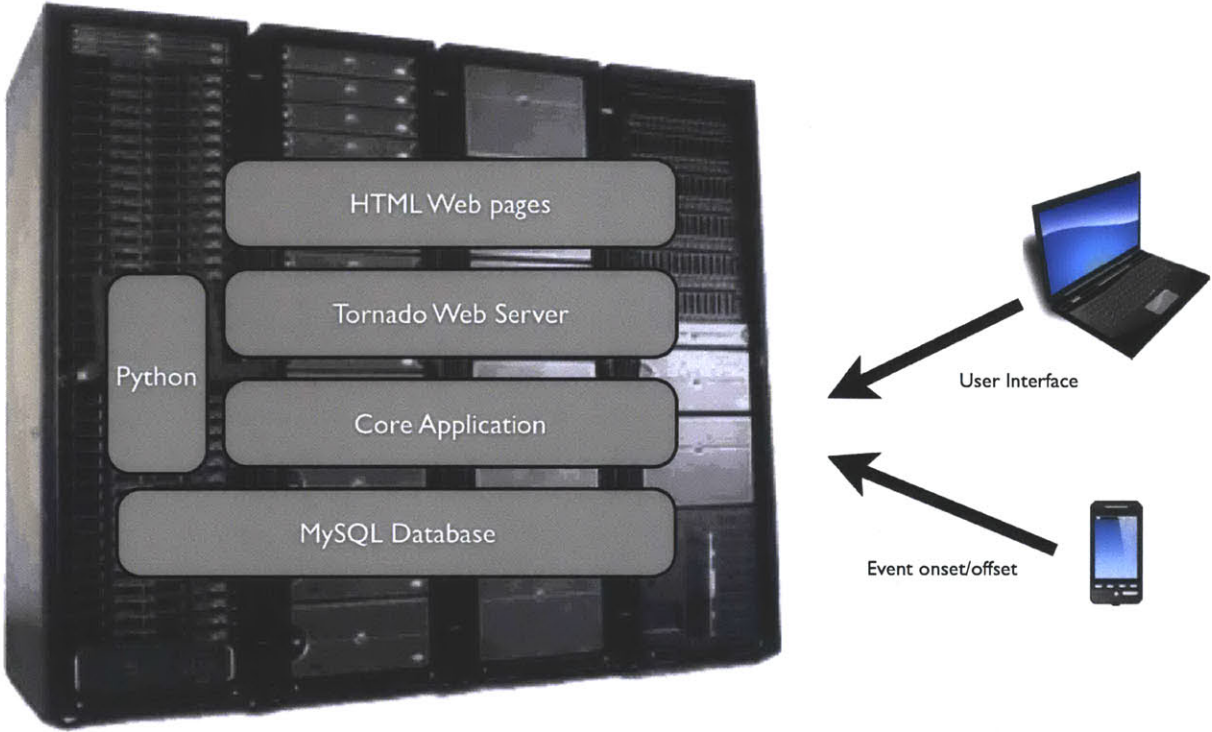


Figure 3.7 FEEL backend server block diagram

3.5 Signal Processing

The FEEL system is designed to determine the high arousal points in a users day. Several algorithms were evaluated to this end. These algorithms were executed on a labeled data set with the end goal of correctly determining the most arousing points of the day. The following algorithms were tested:

1	<ul style="list-style-type: none"> • <i>SMOOTH SIGNAL</i> • <i>FIND LOCAL MAXIMA ABOVE THRESHOLD X IN SMOOTH SIGNAL</i> • <i>SORT LOCAL MAXIMA ACCORDING TO HIGHEST VALUE FIRST</i> • <i>PICK N FIRST LOCAL MAXIMA POINTS</i>
2	<ul style="list-style-type: none"> • <i>SMOOTH SIGNAL</i> • <i>FIND LOCAL MAXIMA AND MINIMA ABOVE THRESHOLD X IN SMOOTH SIGNAL</i> • <i>CALCULATE GRADIENT BETWEEN MAXIMA AND FOLLOWING ADJACENT MINIMA</i> • <i>SORT LOCAL MAXIMA ACCORDING TO HIGHEST GRADIENT FIRST</i> • <i>PICK N FIRST LOCAL MAXIMA</i>
3	<ul style="list-style-type: none"> • <i>SMOOTH SIGNAL</i> • <i>FIND LOCAL MAXIMA ABOVE THRESHOLD X IN SMOOTH SIGNAL</i> • <i>AROUND EACH LOCAL MAXIMA COUNT NUMBER OF LOCAL MAXIMA ABOVE THRESHOLD X/10 IN RAW SIGNAL</i> • <i>SORT ACCORDING TO HIGHEST NUMBER OF LOCAL MAX ABOVE THRESHOLD X/10 FIRST</i> • <i>PICK FIRST N LOCAL MAXIMA ABOVE THRESHOLD X</i>
4	<ul style="list-style-type: none"> • <i>SMOOTH SIGNAL</i> • <i>FIND LOCAL MAXIMA ABOVE THRESHOLD X IN SMOOTH SIGNAL</i> • <i>CALCULATE ACCTIVITY LEVEL AROUND EACH LOCAL MAXIMA BASED ON ACCELEROMETER</i> • <i>BUILD 4 BIN HISTOGRAM OF ACTIVITY LEVELS</i> • <i>REMOVE ALL MAXIMA THAT ARE IN THE HIGHEST BIN</i> • <i>SORT LOCAL MAXIMA ACCORDING TO HIGHEST VALUE FIRST</i> • <i>PICK N FIRST LOCAL MAXIMA</i>

In all algorithms the signal is smoothed in order to eliminate high frequency components such as movement artifacts. To achieve this the Python numpy convolution function was used.

Algorithm 1 selects the highest peaks. The most arousing did not always produce the highest peaks, but rather wider peaks (a higher level of EDA that lasted longer). Algorithm 2 selects the peaks with “slowest decay” (the highest negative gradient). The downside of this approach is that very low peaks are selected as well. Algorithm 3 produced sufficient results – it sorts the peaks according to the number of Skin Conductance Responses (SCRs) counted during 10 minutes (5 minutes prior to the local maxima, and 5 minutes after). In most cases it detected the peaks associated with the arousing events. Algorithm 4 ordered the peaks according to accelerometer activity levels (using the first, second and infinite moments of accelerometer data as a measure for activity). The downside of this approach is that some of the most arousing events involved a high level of activity – for instance: running due to being late to an important meeting. It was decided to use algorithm 3 for the duration of the study.

Whenever the user requests to view a stream of EDA, the FEEL core application performs peak detection in real-time on the signal. Therefore, designing an algorithm with low run-time complexity was important for providing a reactive system and a good user experience.

Initially the signal processing code was written in Python. Preliminary trials suggested that this approach would result in a very slow system response. Processing the EDA for 1 day for a single user took between 30-60 seconds. As a result, the signal processing code was re-written in C, which provides significantly faster execution times. The python Weave module was used in order to call the C signal processing code from within the python code. EDA processing time was reduced to 5-10 seconds, which produced a noticeable experience in system responsiveness.

3.6 The User Interface

The FEEL user interface is implemented as a web application. This approach was preferred over developing a standalone Graphical User Interface (GUI) client application for the following reasons:

1. Platform independence - A standalone GUI application is heavily dependent on the underlying operating system and it would have been necessary to develop such an implementation for multiple operating systems (Windows, Linux and MAC OS-X) to support the various users and each with their own choice of Operating System (OS). A Web application can run on any OS that includes a modern web browser that supports JavaScript.
2. Ease of deployment – No installation is necessary. Users access the application by using a web browser and entering a URL in the browser address bar.
3. Ease of support – in case of bug fixes or new features, only one instance of the software needs to be fixed. Redeployment of the new version is as simple as restarting the back end web server.
4. Low processing power – web applications typically require less processing power on the client. The bulk of the data processing is done on the server and only the results are sent to the client.
5. Mobile device support – modern mobile devices include web browsers that are able to run web applications. An additional benefit is extended battery life as most of the processing is done on the backend server.

The following frameworks were selected:

- HTML
- Javascript
- CSS
- AJAX
- JQuery [39] – lightweight cross-browser JavaScript library for development of web applications
- JQuery UI [40] – a widget library built on top of JQuery

- HighStock [41] – library for creating interactive web charts and visualizing time series data
- JqGrid [42] - an AJAX enabled JavaScript library for visualization of tabular data
- Google Maps Javascript API [43]

The UI is rendered using a combination of HTML, Javascript and CSS, which provide the flexibility to format each displayed element and perform various manipulations (such as hiding, moving, resizing etc) on elements during run-time. AJAX is used to receive data from the backend server in an asynchronous manner. This saves the need to reload the HTML page each time new data is requested and creates a responsive interface.

3.6.1 Login screen

The user may either signup or Login to the system by providing an email address, mobile phone number and password (the Login screen is seen below). The Login screen also contains links to download the FEEL mobile client and the modified version of the K9 mobile email client.

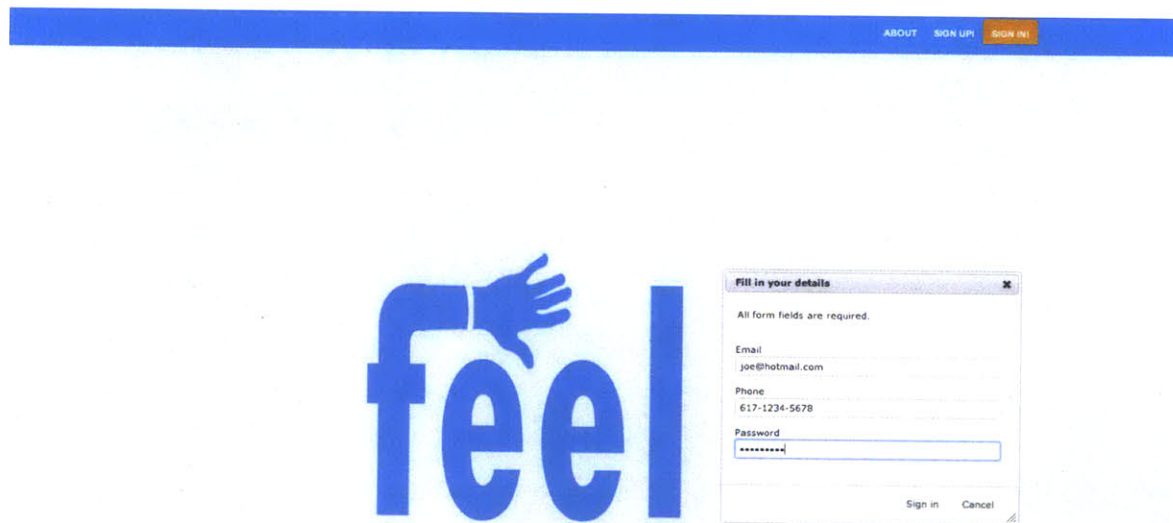








Figure 3.8 The FEEL login screen

3.6.2 The Event Viewer

The event viewer enables the user to view all of the recorded events in a convenient table. The 'Type' column shows what type of event was captured, the 'Time' column shows the time that the event occurred, the 'Duration' column shows amount of time between event onset and offset, and the 'Memo' column shows additional information used for event recall. The 'Memo' column may contain the phone number and contact name in case of a phone call, the calendar entry title in case of a calendar entry, and the email subject in case of a read-email event.

Type	Time ↓	Duration	Memo
	Saturday, May 05, 2012 14:23:23	00:00:25	Unknown Contact - 14083098628
	Saturday, May 05, 2012 10:33:31	00:00:27	Joichi Ito - Re: [MAS-MS] RSVP for Nokia talk
	Saturday, May 05, 2012 10:33:23	00:00:04	Felice Gardner - [MAS-MS] Do you have a very cool
	Saturday, May 05, 2012 10:33:11	00:00:09	Ben Peters - [msgs] Surprise LN2 ice cream!
	Saturday, May 05, 2012 09:08:52	00:00:09	Felice Gardner - [MAS-MS] Do you have a very cool
	Saturday, May 05, 2012 08:57:29	00:00:00	Joichi Ito - Re: [MAS-MS] RSVP for Nokia talk

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View 1 - 20 of 20

Figure 3.9 The FEEL event viewer

The event viewer also enables sorting of the events according to type, time, duration or memo. Clicking on the relevant column header does this. It is possible to switch between ascending and descending sorts by clicking the column header repeatedly. Clicking on an entry in the event viewer will load the corresponding physiological recording data in a frame below the event viewer. The event user was implemented using JqGrid.

3.6.3 The Calendar Widget

This widget enables the user to view the recordings of a specific date. The physiological data and event data is displayed in a frame below the widget. The displayed range is between Midnight of the day before the selected date and midnight of the selected date.

April 2012						
Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

Figure 3.10 The calendar widget

3.6.4 The Electrodermal Activity Display

This frame displays the user's EDA, skin temperature and accelerometer data along with the events that were recorded during the same time frame. Although in the current implementation the frame is used for displaying EDA, it may be used for displaying other time series data as well.

Icons overlaid below the EDA signal represent the various types of events. When hovering the mouse over an event, the event details are displayed. This is done in order to cause minimal obstruction to the EDA signal view. By clicking on a series type in the legend, it is possible to hide/show that series in the frame. The EDA display was implemented using the HighStock framework.

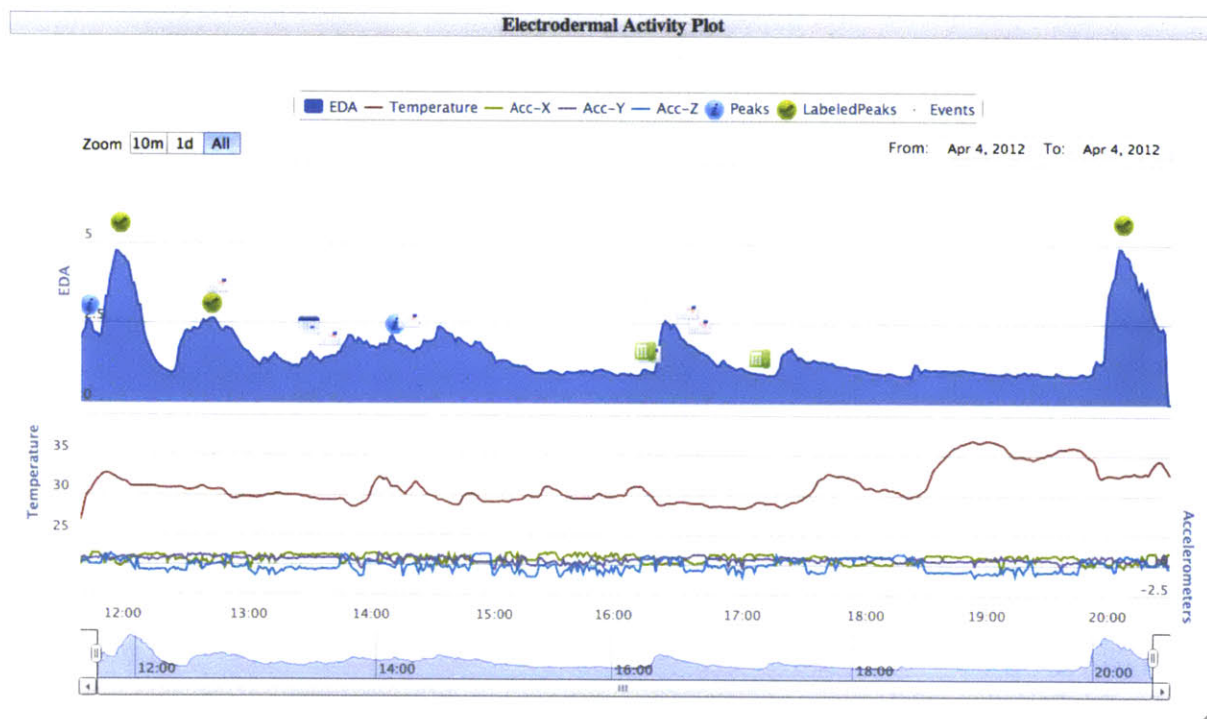


Figure 3.11 The Electrodermal activity display

The following types of zoom are supported:

1. Click and drag – clicking within the EDA plot area and dragging will zoom into the marked area
2. Navigator series - a small series below the main series, displaying a view of the entire data set. It provides tools to zoom in and out on parts of the data as well as panning across the dataset.
3. Range selector - The range selector is a tool for selecting ranges to display within the chart. It provides buttons to select preconfigured ranges in the chart: 10 minutes, 1 day and the full data set for a selected range

3.6.5 The Location Viewer

This frame displays the users historical locations overlaid on a map. Each location is marked by a red pin. When the mouse hovers over a specific pin, the time of the location recording is displayed. When a user selects a date, all of the locations that the user visited during that date are displayed. The locations are also overlaid on the EDA signal using the same red pin icon. When clicking a location pin on the EDA signal, the map viewer is automatically adjusted to display that location in the center of the map frame. It is possible to select between Map display mode, Satellite display mode and Street View mode. Panning and Zooming are also supported.

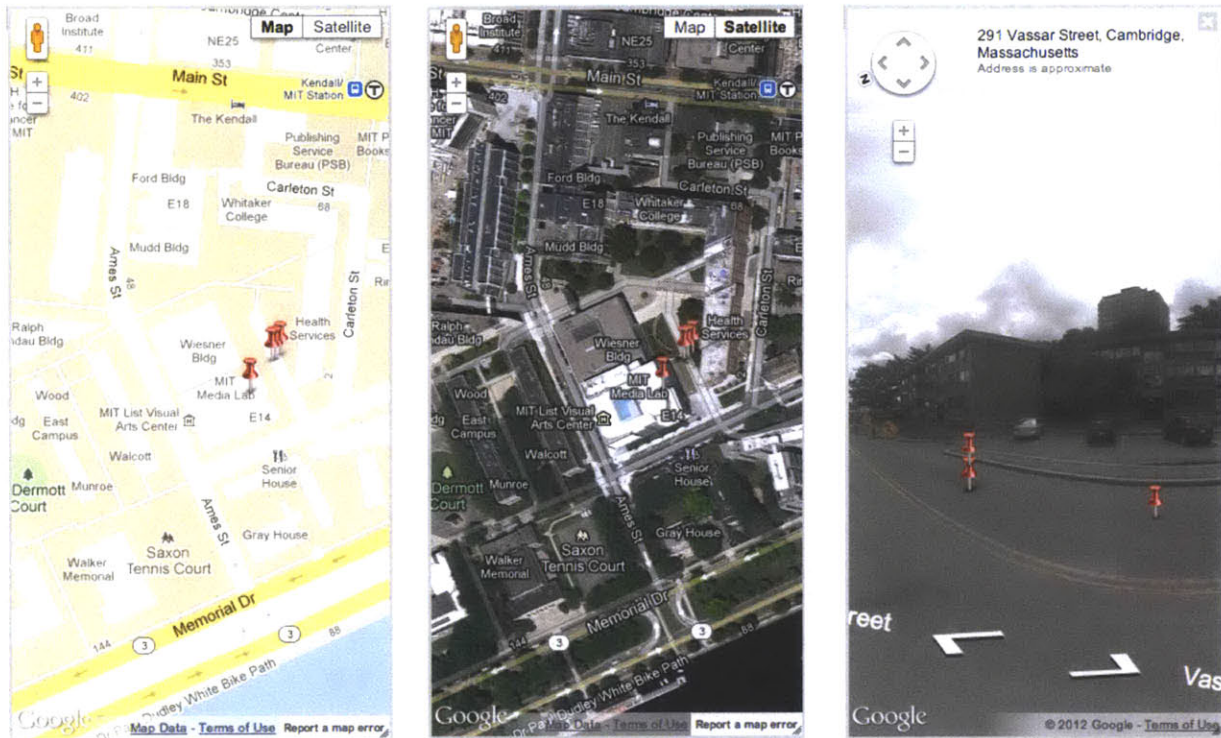


Figure 3.12 The location viewer – Map mode (left), Satellite mode (center) and Street view (right)

3.6.13 User Self Report

The FEEL system performs tonic level peak detection on the EDA signal and selects three peaks for the user to provide additional details. When the user clicks a peak marked with an exclamation mark a dialog containing a form (as seen in the figure below) will be displayed. After the user fills in all the fields and clicks the Save button, the report is sent to the backend end server. Once a report is submitted, the blue exclamation mark is replaced by a green tick mark, which signifies that a report has been already submitted for that peak.

All form fields are required.

Please describe what occurred approximately at 22:58

Rate the accuracy of your label

1 ○ ○ ○ ○ ○ ○ ○ 7

What was your Valence (Negative vs Positive)

○ ○ ○ ○ ○ ○ ○ ○ ○ ○

How confident are you in your above rating for Valence?

1 ○ ○ ○ ○ ○ ○ ○ 7

What was your Arousal (Calm vs Excited)

○ ○ ○ ○ ○ ○ ○ ○ ○ ○

How confident are you in your above rating for Arousal?

1 ○ ○ ○ ○ ○ ○ ○ 7

How clearly do you recall what happened at that time

Not clear at all ○ ○ ○ ○ ○ ○ ○ Extremely clear

Any additional information you would like to note:

Figure 3.13 User event report form

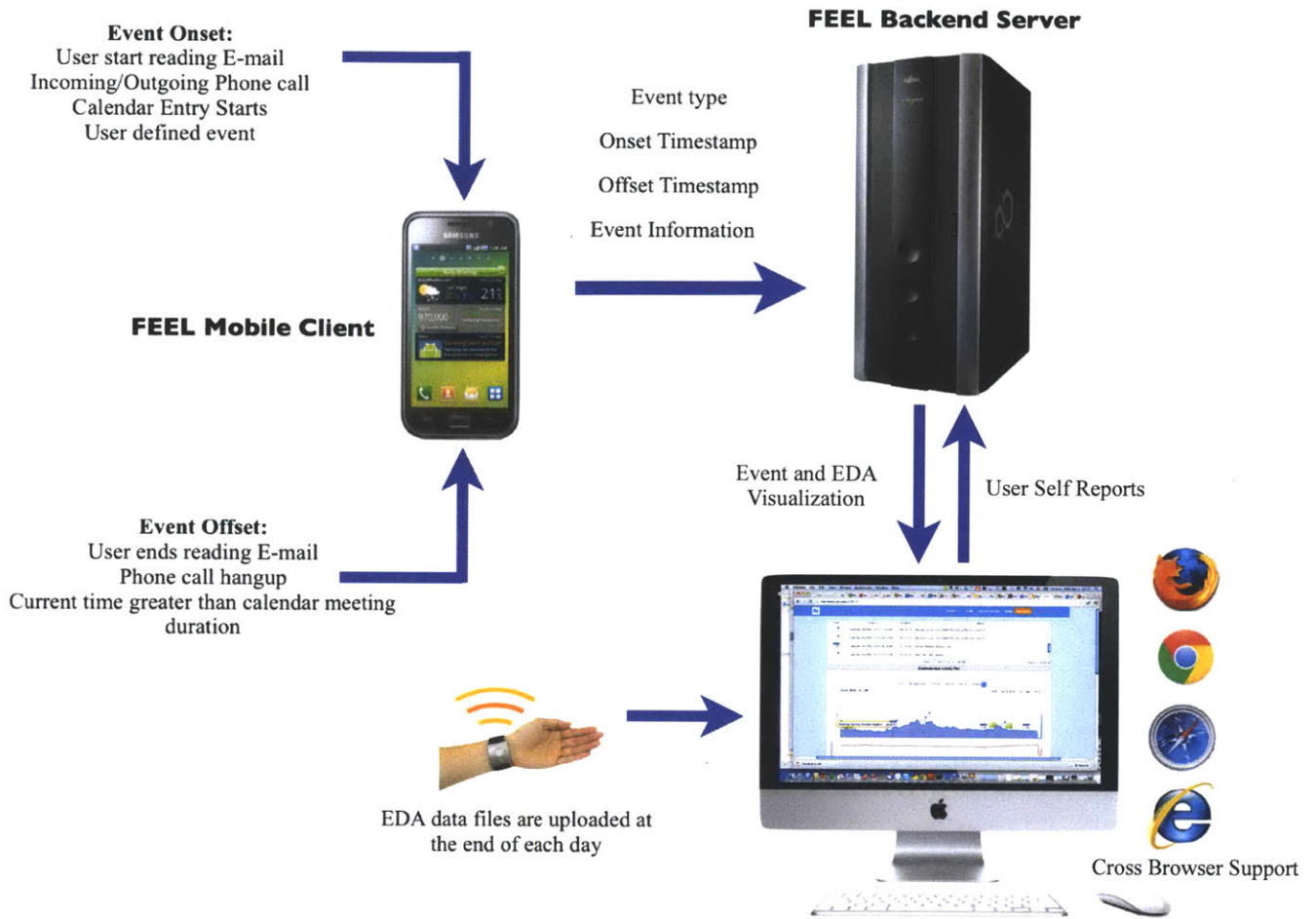


Figure 3.14 FEEL high level system architecture

Chapter 4

Experimental Design and System Evaluation

The study protocol was pre-approved by the MIT committee on the use of humans as experimental subjects (COUHES). The submitted protocol can be found in the appendix of this thesis.

The goal of the system evaluation is twofold:

1. Ensuring that the system operates as expected and that it fulfills its design goals
2. Obtaining feedback from the users as to their experience while using the system in order to assess its usefulness and receive user feedback.

This was a comparative study in which I intended to show that the FEEL platform increases the data collection effectiveness and the quality of data that is collected.

4.1 Participant recruitment

Participants were recruited by sending emails to multiple mailing lists at MIT. In order to be eligible, candidates had to satisfy the following constraints:

1. Participant owns an android mobile phone
2. Participant uses the Google calendar application to manage activities
3. Participant reads emails mainly on their mobile phone

Participants would not be eligible if they:

1. Are taking ADHD medication
2. Are taking any medication that can have arousing or calming effects
3. Have a problem wearing a wrist sensor (skin condition, etc.).

Each potential candidate was invited to a screening session that lasted 20 minutes. During the session, the candidate received an explanation of the study protocol and requirements. In addition, the candidate was asked to wear a Bluetooth EDA wrist sensor on each wrist. The goal of this was to determine if the candidate has sufficient EDA response to stimuli. At a random point during the screening session, a loud tone was generated in order to evoke an EDA startle response. Candidates that did not exhibit sufficient responses could not participate in the study.

We recruited ten graduate students for the study. Their average age of the participants was 30.8 (SD=4.2), the youngest was 25 and the oldest was 35. All of the participants had a right dominant hand. Nine of the participants were male, and one was female.

4.2 The experiment

Participants were asked to wear a pair of commercial electro-dermal activity (EDA) wrist biosensors on their left and right wrists for a period of 10 days. The sensors measure EDA, skin temperature and 3-axis accelerometer and store the readings on an internal SD card. The data can be downloaded from the sensor via a USB cable. All of the sensors were time synced using the same machine in order to synchronize between the left and right sensor readings. Participants were instructed to wear the sensors for as long as possible and to take them off and charge them during bathing times.

In addition, we directed the participant to download the FMC application and K9 email client application from the FEEL web site and install them on their android mobile phones. The K9 client was configured to download emails from the participants' accounts. Each participant was directed to only read emails using the K9 client for the duration of the study.

After installation, we asked the participants to read a random email and also to dial a non-existent phone number: '12345'. This served the dual purpose of checking that the FMC was both recording the context on the participants' phones as well successfully transmitting the data to the FEEL back end server.

The FMC application collected the following data:

- Calendar event details - subject, start time, end time, location, and participants
- Phone call details - start time, end time, and recipient
- Email reading - start time, end time, subject, and recipients
- Location – latitude, longitude, accuracy, and time

The study participants divided into two groups of five. Each group would have access to a different type of interface during the stages of the study. Participants were not told that they would be using different interfaces at different stages.

Interface I – non-contextual viewer

This interface as can be seen in the figure below, does not include any contextual data. The user can only view EDA, temperature, and accelerometer data as well as arousal self report data.

This interface is representative of many of the wearable sensors systems available today, which mostly provide access to the raw sensor data.

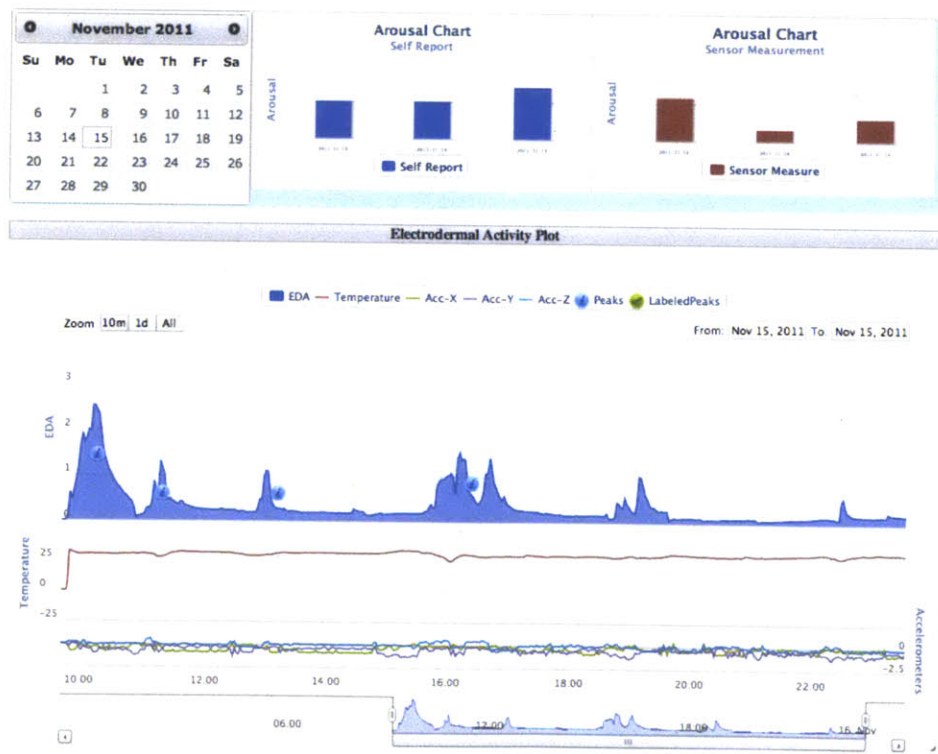


Figure 4.1 Non-contextual viewer

Interface II – contextual viewer

This interface presents the bio-physiological signal and contextual information overlaid on top of it.

The signal includes EDA, skin temperature, accelerometer and overall arousal level.

The contextual information includes email readings, phone calls, calendar entries and geo-location information.

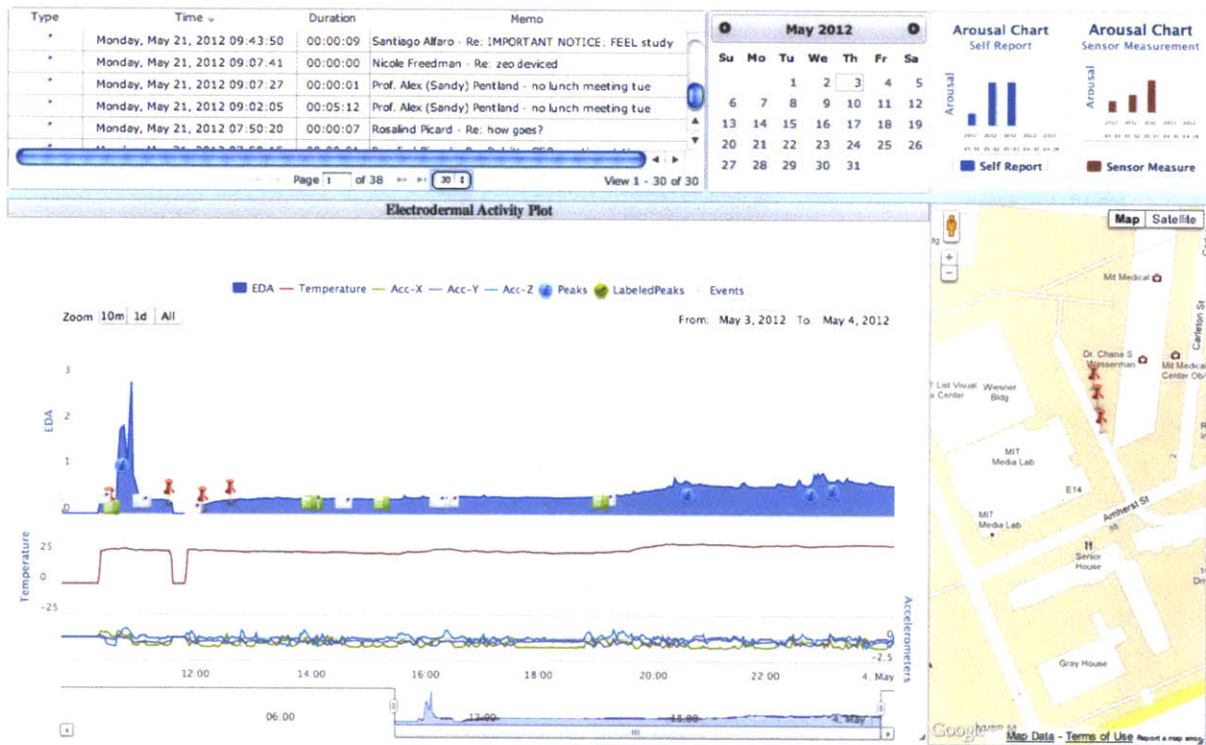


Figure 4.2 Contextual viewer

Stage 1 (days 1-5)

At the end of each day, the participants were asked to upload their sensor recording files to the FEEL web site. After uploading the files, the participants were asked to rate the arousal level of their day on a 1-7 Likert scale. The user could not view his EDA until after completing the arousal rating in order to prevent bias (seeing many peaks may suggest that the participant had an arousing day).

How Arousing Was Your Day?

Not Arousing at all Extremely Arousing

*Arousal: physiological and psychological state of being awake or reactive to stimuli. Examples of emotions with high arousal are angry or excited. Examples of emotions with low arousal are relaxed or depressed. Note that arousal can be either positive or negative.

Figure 4.3 Arousal rating dialog

After completing the arousal rating, the users were requested to view their EDA recording and to annotate 3-4 peaks that were marked on the plot by the software. The algorithm detects local maxima, and sorts them according to the number of SCRs (Skin Conductance Response) in a window of 10 minutes. The peaks with the highest number of SCRs are selected for annotation.

During this stage, the first group of participants could only access the non-contextual interface, while the second group could access the contextual interface. This was done in order to test if whether the participants had access to the contextual data would affect their event recall.

When a user clicked a marked peak an annotation dialog would open (Figure 11 shows the annotation dialog). The users were asked to describe what occurred approximately at the time of the peak, and to rate the accuracy of their label on a 7-point Likert scale. Next, the users were asked to rate their valence at the time of the peak (negative vs. positive) and their arousal (calm vs. excited). We used a 9 point Self Assessment Manikin (SAM) pictorial scale as developed by Bradley and Lang [44] in order to assess the users emotional reaction to the event. We also asked the user to rate their confidence in their valence and arousal scores on a 7-point Likert scale. Finally, the users were asked how clearly they recalled what happened at the time on a 7-point Likert scale and whether they had any additional information to add.

Stage 2 (days 6-10)

In this stage participants were asked to upload their sensor data at the end of each day, similar to stage 1, but with the following differences:

1. We wanted to test if the contextual interface enabled a higher level of recall of the events: the participants were asked to annotate the peaks for each day after two days had passed, and not at the end of the day.
2. The first group of participants, which could previously only access the non-contextual interface, got access to the contextual interface. The second group, which previously accessed the contextual interface, could only access the non-contextual interface. This was done in order to cancel out any recall improvement that the participants might have due to training themselves to remember information after prolonged use of the non-contextual system.

4.3 Ethnographic Study

At the end of the study we performed an ethnographic interview to obtain qualitative information on the usability of the new tool. In the first part of the interview we asked the participants to fill in two sets of surveys. The first set of questions was asked to assess system usability. We used the system usability scale [45] (SUS), which is a simple, ten-item scale giving a global view of subjective assessments of usability. SUS Questions are answered on a 7-point Likert scale and yields a single number representing a composite measure of the overall usability of the system.

The second set of questions was used to assess the user's experience during the use of the system.

In the second part of the interview we asked the participants open-ended questions regarding their personal experience during the study. We wanted to determine which features the users found useful, which features were difficult to user or provide little value, and what features they would have liked to see implemented.

The participants were also asked to fill in a Toronto-Alexithymia (TAS-20) [46] questionnaire to assess their ability to identify and describe emotions.

Chapter 5

Results and Discussion

The FEEL system collected data from 10 participants for 10 days, yielding a total of 100 days of data. There were a total of 337 annotations and a total of 947 Mbytes of EDA sensor data that was uploaded to the system. The mobile client collected the following data:

Event type	Total number of events
Location events	4217
Email reading events	2595
Phone calls	983
Calendar entries	211

The system functioned as intended, exhibited stability and no serious exceptions were reported. There was no need for any reboot or any modifications to the software during the study.

5.1 System Effectiveness

I wanted to assess whether the system affects user recall of events and hypothesized that if contextual information is related to emotional event recall, then providing contextual information to users will improve their confidence level when annotating EDA peaks.

In order to test this hypothesis, the study population was divided into two groups. One group (A) had access to the contextual information alongside with the EDA signal, while the other group (B) had access to the EDA signal alone. During the first stage of the study, both groups were asked to annotate their recorded EDA at the end of each day. For each annotation the participants were asked to rate how clearly they recall the event, how accurate is the annotation label, and what their confidence level is for both the arousal and valence rating of the event on 7 point Likert scales. The average ratings and medians can be seen in the following table:

	Group A (contextual)	Group B (non-contextual)
Annotation Clarity	5.439 (1.370) / 6	5.285 (1.632) / 6
Annotation Accuracy	5.682 (1.413) / 6	5.654 (1.392) / 6
Valence Confidence Rating	5.451 (1.491) / 6	5.571 (1.337) / 6
Arousal Confidence Rating	5.463 (1.475) / 6	5.500 (1.207) / 6

Table 1 Stage 1 average ratings (standard deviations) / median

Running the Wilcoxon rank sum test (equivalent to the Mann-Whitney U test) on both groups of the participant ratings during stage 1 produced the following results:

	P-Value (0.05 significance)	Null Hypothesis
Annotation Clarity	0.8060	Accepted
Annotation Accuracy	0.9265	Accepted
Valence Rating Confidence	0.5172	Accepted
Arousal Rating Confidence	0.8166	Accepted

Table 2 Stage 1 Wilcoxon rank sum test

It is evident that there is no significant difference between the groups in terms of the annotation clarity, accuracy, and valence and arousal rating confidence. It seems that providing contextual information did not affect the recall of the days' events; this may be because only a short period of time had passed between the event itself and its annotation.

During the second stage of the study, the participants were requested to annotate their EDA signals only after two days had passed, instead of at the end of the day for the events being annotated. In addition, the interfaces were switched: group A was given the non-contextual interface and group B was given the contextual interface.

The average ratings and medians can be seen in the table below:

	Group A (non-contextual)	Group B (contextual)
Annotation Clarity	3.151 (1.762) / 4	4.666 (2.209) / 6
Annotation Accuracy	3.5941 (1.884) / 3	5.422 (1.835) / 5
Valence Rating Confidence	3.683 (1.891) / 4	4.8777(1.841) / 6
Arousal Rating Confidence	3.620 (1.869) / 4	4.755 (1.743) / 5

Table 3 Stage 2 average ratings (standard deviations) / median

Running the Wilcoxon rank sum test (equivalent to the Mann-Whitney U test) on both groups of the participant ratings during stage 2 produced the following results:

	P-Value (0.05 significance)	Null Hypothesis
Annotation Clarity	4.0649e-05	Rejected
Annotation Accuracy	1.0471e-09	Rejected
Valence Rating Confidence	2.8929e-05	Rejected
Arousal Rating Confidence	5.3354e-05	Rejected

Table 4 Stage 2 Wilcoxon rank sum test

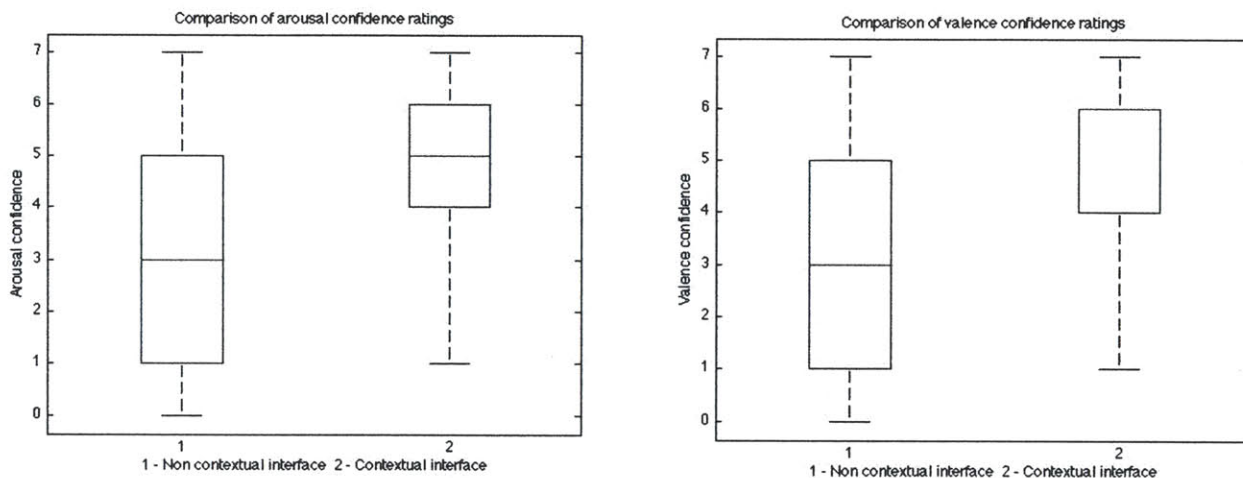


Figure 20 Comparison of annotation arousal confidence ratings (left) and valence confidence ratings (right) between groups A (non contextual interface) and B (contextual interface) during stage 2 of the FEEL study

It is evident from figures 16 and 17 that during stage 2 groups A and B do not have the same mean. On average the valence rating confidence and arousal rating confidence are higher by 33% and 30% respectively when the context is provided. In addition, the clarity and accuracy of annotations is higher by 47.8% and 50.8% respectively.

These results suggest that by providing users with contextual information the FEEL system enables the users to annotate bio-physiological signals at a greater effectiveness. Even though the captured contextual information is only partial, and may not directly result in a physiological change, it provides the basis for a user to feel that they can better recall what they were doing at the time.

5.2 Arousal Self report

At the end of each day, the users were asked to upload their EDA data. After uploading the data, each participant was asked to rate how arousing their day was on a 7-point Likert scale (from 'not arousing at all' to 'extremely arousing'). We were interested in measuring how good people were at estimating their own arousal levels. To this end it was necessary to quantify the EDA for each day as a single number. Traditionally, the magnitude of the EDA signal was most commonly used [26] but recently the area bounded by the EDA curve is used as a measure [47].

For each participant the correlation coefficient between the 10-day arousal self reports and the following measures was calculated:

1. Total area under the curve – using the trapezoidal rule to approximate the total area under the EDA curve for each day
2. Most recent area under the curve - using the trapezoidal rule to approximate the total area under the EDA curve for only the most recent 25% of the measured signal for each day
3. Recent area under the curve - using the trapezoidal rule to approximate the total area under the EDA curve for only the recent 50% of the measured signal for each day
4. Max EDA – finding the maximal amplitude of the EDA signal recorded for each day

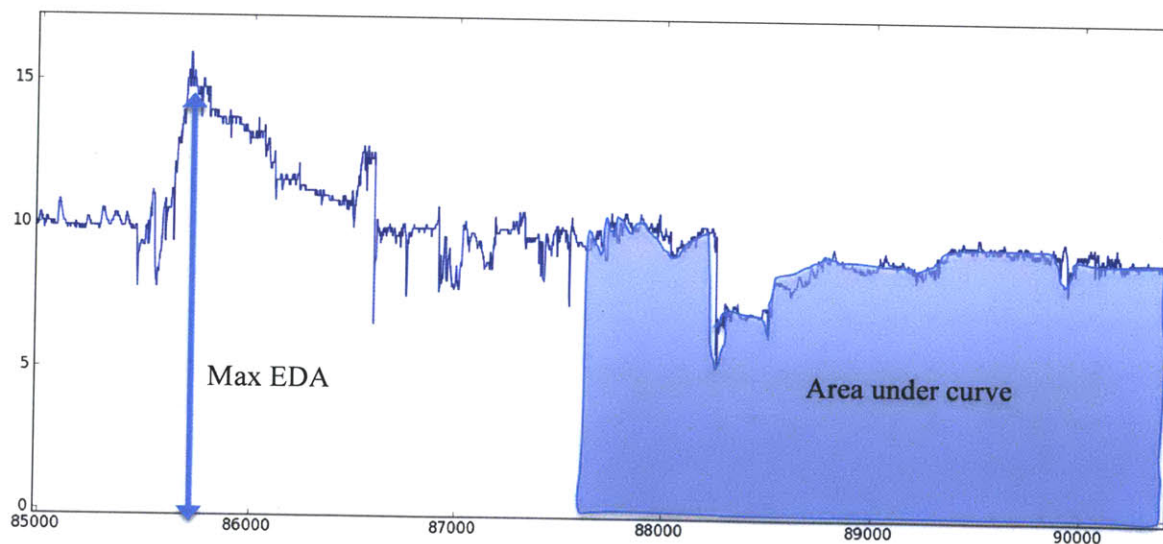


Figure 5.2 EDA quantification measures - maximum EDA and area under the curve

If people are able to accurately evaluate their own arousal levels, then we would expect to see a significant correlation between the arousal self-reports and the quantified EDA sensor measurement. The correlations can be seen in the chart below, comparing the four methods of summarizing the EDA with people’s self-reported arousal for each day.

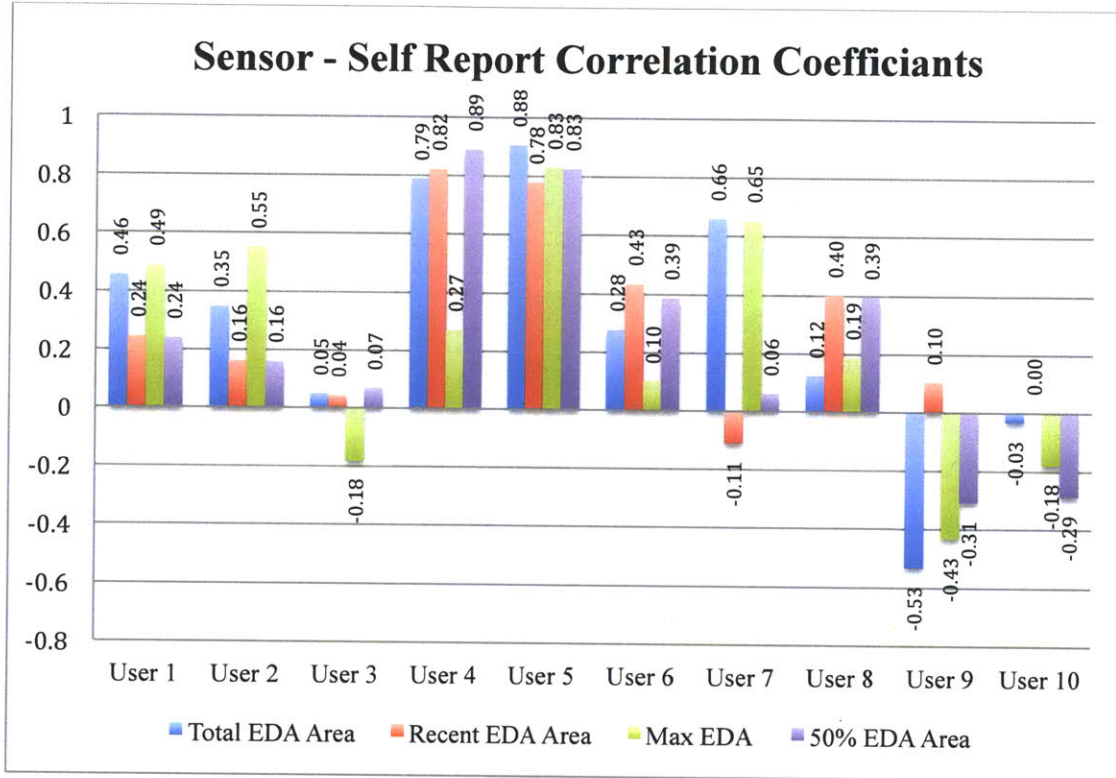


Figure 5.3 EDA sensor – 10-day arousal self report correlation

It is interesting to note that most of the participant’s 10-day self reports were only moderately correlated with their own 10-day EDA sensor measurement suggesting that they did not correctly identify their arousal levels throughout the study. However, across the study population there aren’t enough samples (10 people) for us to determine that this result is statistically significant. When selecting total EDA area as a measure for arousal, only the three participants users 5, 4 and 7 exhibited strong correlation that is statistically significant – 0.887, 0.788, and 0.659 (P=0.05) respectively.

At the end of the study, the participants were also asked to fill in a Toronto Alexithymia survey (TAS-20) [46]. The TAS is a 20-item questionnaire that is used to measure Alexithymia, a condition whereby a person has trouble identifying and describing his or her own emotions, and tends to minimize emotional experience and focus attention externally.

The TAS-20 has 3 subscales:

1. Difficulty Describing Feelings subscale
2. Difficulty Identifying Feeling subscale
3. Externally-Oriented Thinking subscale that is used to measure the tendency of individuals to focus their attention externally

The sum of the scores on each subscale results in a total score that is used as follows:

- Score less than 51 = non-alexithymia
- Score equal to or greater than 61 = alexithymia
- Scores between 52 and 60 = possible alexithymia

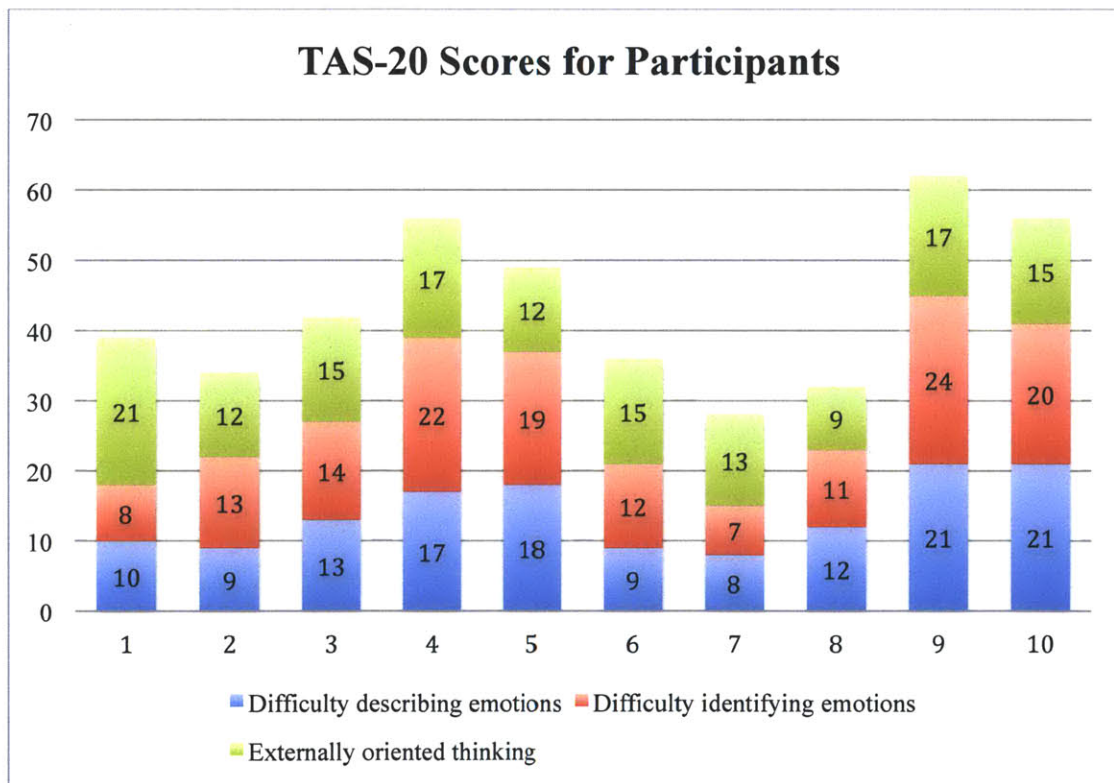


Figure 5.4 TAS-20 scores for study participants

When calculating the correlation between the TAS-20 scores for each user and the sensor arousal-self report correlation based on the total EDA area under the curve an interesting pattern emerges. Initially, it seems that only moderate negative correlation exists (-0.32).

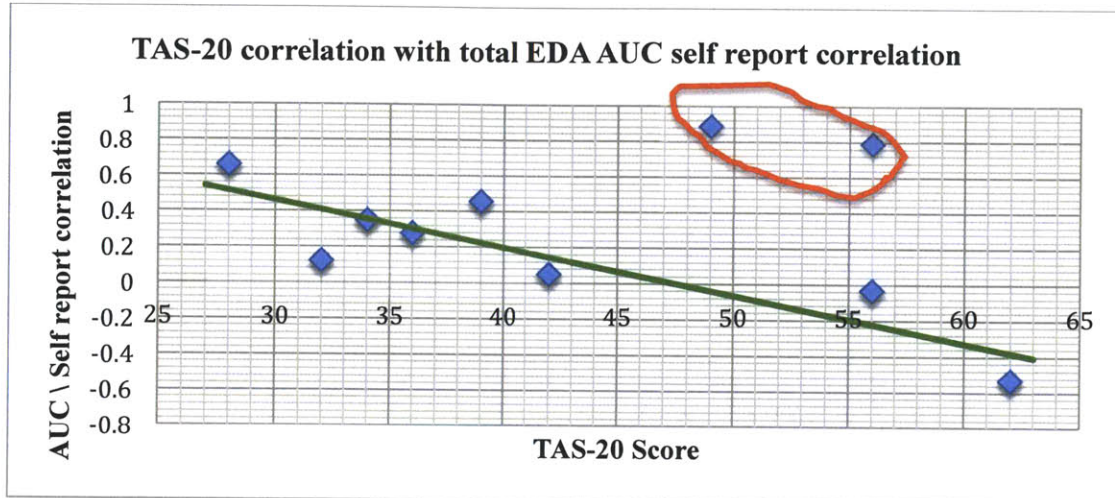


Figure 5.5 TAS-20 correlation with total EDA area under curve self report correlation

Exploring the correlation plot reveals that a stronger correlation may exist. The size of the population limits our ability to remove outliers but the data suggests that a larger population size may result in a stronger correlation. By removing the two points (circled in red) the correlation increases to -0.867, which is statistically significant ($p=0.01$). The correlation between total EDA area under the curve-self report correlation and TAS-20 difficulty identifying feelings sub scale was even stronger: -0.93 .

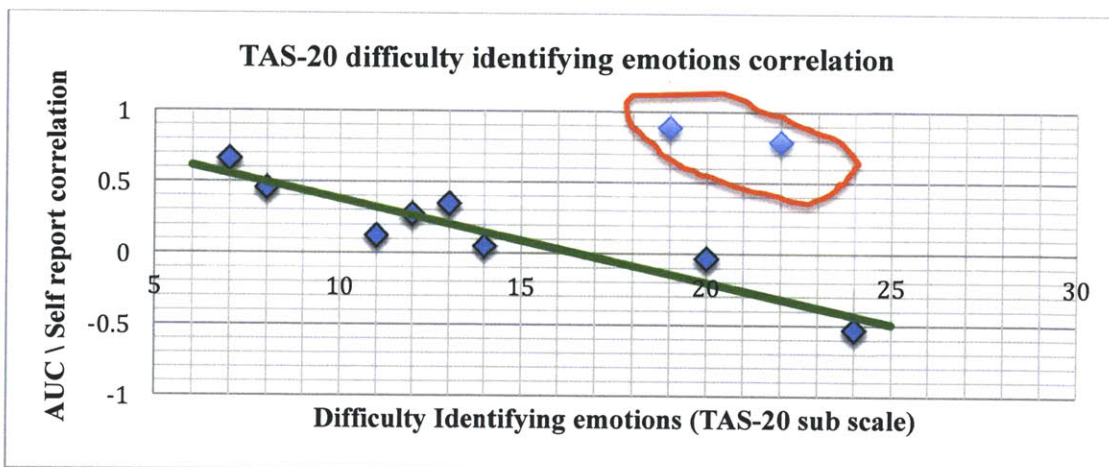


Figure 5.6 TAS-20 difficulty identifying emotions correlation with total EDA area under curve self report correlation

This suggests that there is correlation between a participant's ability to determine his own arousal level and the score on the alexithymia test. This outcome is not surprising given that participants with high alexithymia scores have difficulty in describing and identifying emotions and therefore may have difficulty in estimating their own arousal level.

It is interesting to note that the users 4 and 5 (represented by the points in the red circle in figures 5.5 and 5.6) succeeded in evaluating their own arousal level despite having a relatively high score on the TAS-20. During an interview with these two users, each of them claimed that their days were substantially different from one another: some days were very arousing, while others were very relaxing. This made it easier for them to evaluate their arousal levels during each day. Further analysis of the data supports this claim: these two users had the two highest average of maximum EDA readings over 10 days as well as the highest standard deviation of EDA readings between days.

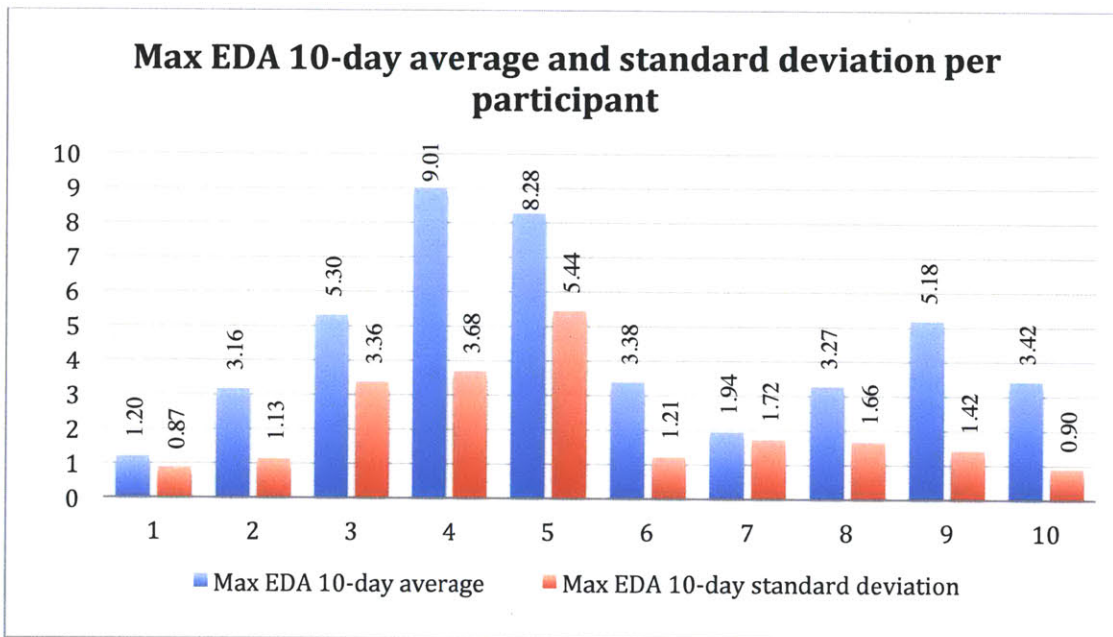


Figure 5.7 Max EDA 10-day average and standard deviation per participant

5.3 User Experience

I conducted a system usability survey, a user experience survey, and interviewed each participant at the end of the study. The results of these surveys and interview are summarized in this section.

Table 3 summarizes the responses of the participants to the user experience survey questions.

Question	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	Median
This application is fun to use	0	0	0	2	1	5	2	6
I would recommend this application to my friend	0	0	0	3	1	4	2	6
I prefer maintaining my own journal for recording context	2	2	1	3	1	1	0	3.5
I think FEEL is more reliable than maintaining my own journal	0	1	1	1	2	5	0	5.5
I would use this application regularly	0	0	2	0	1	6	1	6

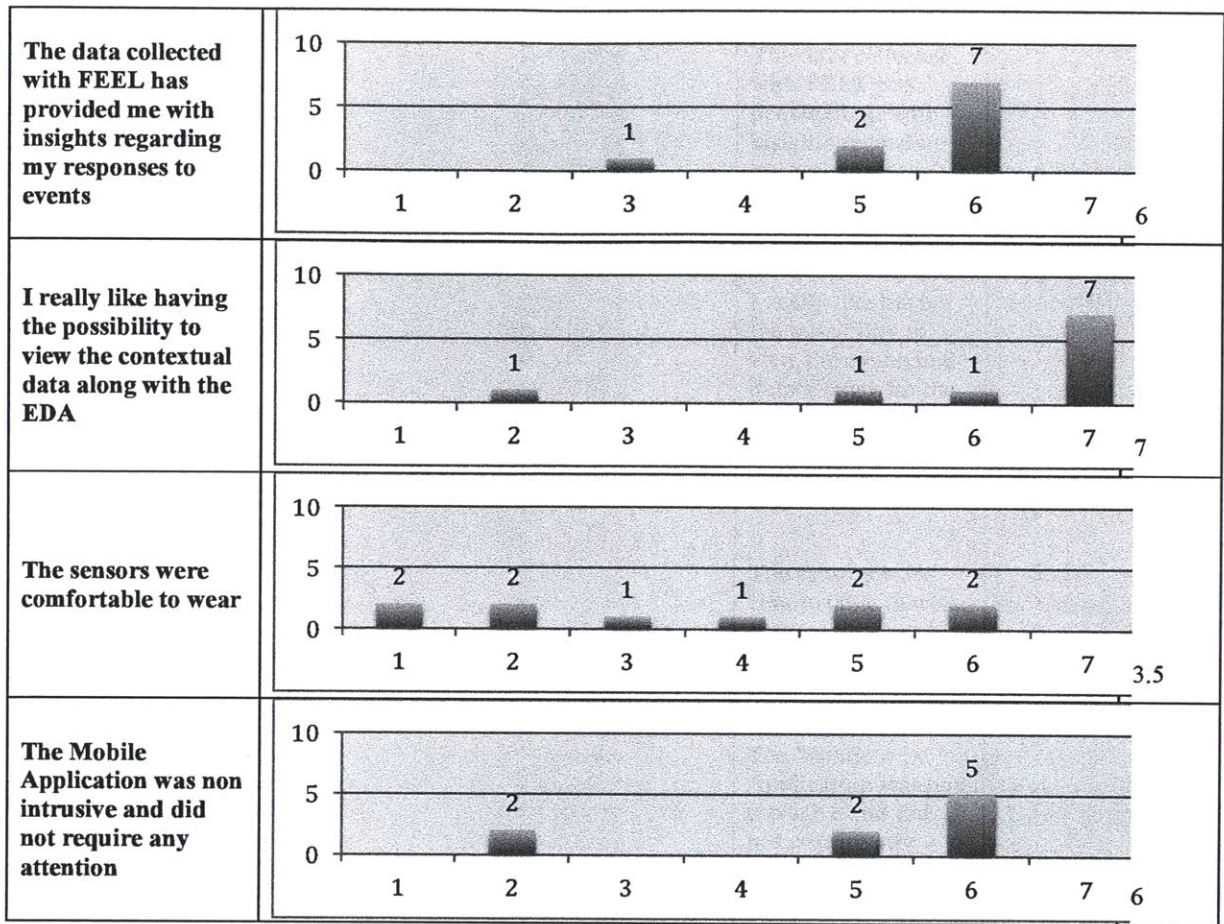


Table 5 User experience survey responses

All of the above feedback was positive, in the direction that we had hoped. The only item that was not as positive as we would have liked was the comfort of the Q sensors, which was rated average overall. Of the two form factors being worn, most of the POD sensor wearers gave it a low score, probably due to the large relatively stiff wrist package that is currently used to house the pod, while most of the curve wearers scored it as comfortable, with the exception of one who had irritated skin and the other who had a malfunctioning sensor which affected his entire experience.

The users were asked to fill in a system usability survey during the study completion interview. The following plot shows the System Usability Score for each of the users in the study (between 0-100)

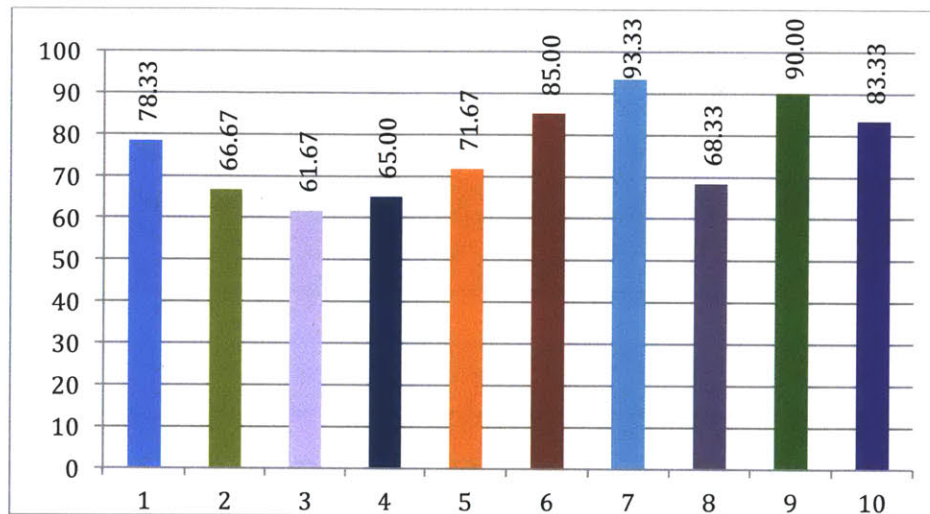


Figure 5.8 System usability score per user

As the results above show, the system usability score ranged between 61.66 – 93.33 and the average score was 76.33 (standard deviation = 11.2).

The participants were asked what they liked about the application (direct quotes):

“Having a plot with everything laid on it”

“The application can tell you when you were excited.”

“Without the contextual information I could not remember anything when I needed to annotate the peaks”

“I enjoyed going over the data every night”

“Provides a really easy way to go back and look at things that are either stressful or exciting”

“The fact that the events were timed and geo-tagged was very good”

“The system gives me some self-awareness of how my emotions evolve over time and my response to certain types of events”

“The features were pretty easy to use”

“I really liked the GPS feature. I was surprised at how much that told me and helped me with recall especially”

“I like exploring what happens over the day at the end of the day”

“I could remember very well where I was and what I was doing”

The participants were asked what was the least favorite part of the application (direct quotes):

“Logging in – is asked my for my email and phone number again and there is no way to save the information”

“if you uploaded your data you would have to click back on that day in order to get it to load”

“I would get confused about what time I seeing; the scale on the bottom was different than the scale on the top”

“When I’m trying to click on the annotation mark, sometimes you have to zoom in”

Most participants liked the system overall and did not have any specific parts that they did not like.

The participants were also asked what feature they would add (direct quotes):

“I would try to do some analytics on some of the other data besides your arousal.”

“if the system knew what SMS’s you were sending would fill in a lot of the (context) gaps that were missing”

“if you did some analysis on the accelerometer data it may help provide some other interesting information”

“I would like to see some additional ways to add in my own journaling information”

“it would be nice to be able to compare between one day and another, or compare between similar situations or events”

“it would be nice if it could record the user voice but no one else’s voice due to privacy concerns... that gives you so much more contextual information.”

“an app that lets you easily log things with a contextual tree would be really helpful... you would get a cup of coffee and pull it out and hit coffee (on the screen).”

“a desktop context recorder (such as email and browser activity)... that is 90% of my life”

“it should be customizable, I could drag and resize the calendar for example”

“a share option – share specific parts with friends”

“not have to take off the sensor for the data to be uploaded”

“you can do it pre-emptively... you should take it easy... predictive abilities would be very nice”

5.4 Summary and Contributions

In this work, I have made several contributions. First, I have designed an architecture for a system for the acquisition, processing and visualization of biophysiological data and contextual information. I have also implemented all of the system elements: a mobile client for context acquisition, a backend application for storage and processing of the physiological signal and contextual information, and a novel user interface that displays the contextual information overlaid onto the biophysiological signal.

In addition, I ran a user study to test the system's usability, effectiveness and the robustness of all its elements. As part of the study, users were required to wear an EDA wrist sensor, install a mobile application and annotate peaks in their EDA. The system collected 100 days of user data and exhibited durability and functioned as planned throughout the study. The system's usability was evaluated by using the System Usability Scale and achieved a good score. Most of the users reported that they enjoyed using the system and that there were no major improvements that they would recommend.

Second, I showed that the FEEL system enables the users to annotate bio-physiological signals at a greater effectiveness than the current state of the art. It provides the basis for a user to feel that they can better recall what they were doing at the time.

Finally, I showed that there is a correlation between a person's ability to determine their own arousal level and their score on the Toronto-alexithymia test: the less alexythymic they were, the better their correlation between the EDA and their self-reported arousal.

Chapter 6

Future Work

The work described in this thesis lays the foundations for designing systems that enable the acquisition, processing and display of bio-physiological signals and contextual information. There are two apparent paths in which this work may be extended; the first is to expand the capabilities of the system in terms of capturing context and bio-physiological signals. This may be achieved by utilizing additional sensors and additional phone functionality. The second is expanding the use cases of the system by adding different applications that utilize the platform. This section will describe future directions for each of these paths.

6.1 System Capabilities

6.1.1 Acquisition of Additional Contextual Information

The current contextual acquisition functionality serves to enhance the recall of events that occurred within the surrounding time frame. At times, the acquired context may be the actual event we are interested in capturing. For instance, a specific phone call that caused a significant change in valence or arousal. If we are to improve the likelihood that a relevant event will be recorded, we should utilize additional sensors. Further analysis of such events may also provide additional data on the users reactions.

Proximity detection – detecting if a group of people is located in the same geography can provide valuable contextual information. It is possible to determine if a user is in the midst of a social interaction such as a meeting, with whom, and for how long. Most mobile phones are equipped with Bluetooth chipsets. In 2010, 906 million mobile phones were sold and almost 100 percent of them were Bluetooth capable [48]. It is possible to utilize Bluetooth for performing proximity detection. Using the Bluetooth mac address which is transmitted intermittently when the phone is in discovery mode and reading the transmission signal strength [49], it is possible to determine which phone users are located in proximity of one another. This approach has several advantages over pure calendar entry based meeting detection. First, users do not always update their calendars to reflect last minute

changes in their schedule. Second, many social interactions are spontaneous and as such do not appear in the calendar. By performing proximity detection in real time, and querying the calendar, it is possible to avoid a manual update.

Facial expression recognition – It is extremely difficult to infer valence from an EDA recording. Using the frontal phone camera and techniques similar to those described by Nicolaou et al. [50], it is possible to determine the facial expression of the user during interaction with the phone and extract smiles. However, smiles do not always imply positive valence, and it is likely that dynamic smile information will be needed, together with contextual information, in order to more accurately determine valence from facial expressions [51]

Sentiment Analysis – Textual sentiment analysis techniques such as those described by Pang and Lee [52] provide a method for determining the valence and dominance of a passage of text. Performing sentiment analysis on all textual content such as emails, SMS, instant messages and web pages may provide important insights into the users affective state. This technique is by no means limited to textual content only. It is possible to perform speech to text conversion on captured audio signals such as phone calls, or meeting recordings and perform sentiment analysis on the resulting text.

Photo and Video Capture – Most mobile phones contain cameras that are able to shoot both still image and video. Users are increasingly utilizing their mobile phones for this purpose instead of using dedicated cameras. The FMC can be extended to send photos and videos to the backend server where they will be integrated with other contextual information. In contrast with some life-logging approaches in which cameras are constantly recording, the advantage of this approach is that the user initiates the capture and this increases the probability of capturing “relevant context”.

Speech Analysis for Emotion Detection - Significant work has been done in the field of emotion detection in spoken dialog. Lee and Narayanan [53] used language and discourse information in conjunction with acoustic correlates of emotion in speech signals for analyzing data collected from a commercially deployed call center for automatic classification of caller turns as conveying either negative or non-negative emotion. Liscombe et al. [54] classified the emotional state of user turns in

a corpus of dialogs using a combination of standard lexical and prosodic features augmented by contextual features that exploit the structure of spoken dialog.

Using techniques similar to the ones described above, it is possible to tag voice calls with affective state meta-data. An additional enhancement would be to record samples of conversations or meetings for performing speech analysis and detecting the overall sentiment of the interaction.

6.1.2 Acquisition of Additional Bio-physiological Signals

The currently implementation of the FEEL system was tested using EDA sensors. However, it is possible to use other bio-physiological sensors that produce time series data as well. A heart rate sensor and respiration sensor could be used both for health and healthiness applications, and used to complement the EDA for affective state estimation.

Blood glucose levels can be read by a device such as IBGStar[55] which is plugged directly into the mobile phone and can digitize blood glucose test strip results. Wearable ECG and blood pressure [56] sensors can be used to track user health.



Figure 28 IBGStar blood glucose level strip reader

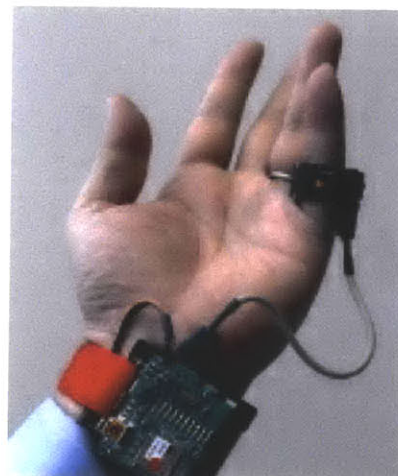


Figure 29 Cuff-less wearable blood pressure monitor

6.2 New Applications

6.2.1 Affective Meta Data Tagging

Hangal et al. [57] suggest that it is a challenge to browse through large unstructured corpuses of text such as email and SMS archives and retrieve useful information. This is especially important since a large portion of our digital history is textual information. The authors propose a system that uses sentiment analysis to provide an entry point to the text archives and for visualization of the full corpus. Weerkamp et al. [58] claim that retrieval effectiveness is improved when utilizing contextual information. The approach of Hangal et al. is limited by the fact that it can only analyze the sentiment of the text. It does not take into account the affective state of the reader when receiving the message. For instance, a highly dominant and negative valence rated email may have little impact on the affective state of the reader. The FEEL system can be utilized to apply meta-data tags containing both the contextual information and the affective state of the reader as may be determined by bio-physiological sensors. This approach need not only be applied to textual information. It may be applied to multi-media as well. FEEL can tag photos with the user's arousal level as they are shot. The user can retrieve photo's based on contextual information and arousal level: "computer, please show me all of my most exciting photos!". It is possible to tag content as it is generated or consumed by the user.

6.2.2 Real-time Response and Intervention

The current implementation of FEEL acquires, aggregates, processes and visualizes contextual and bio-physiological data. The contextual data is streamed in real-time and the bio-physiological signal is recorded on a memory card within the sensor, and uploaded by the user at a later time. Data is presented to the user in a concise and intuitive format that enables the user to perform additional analysis. This implementation can be extended to analyze events as they occur and preform predictions. It is possible to stream the bio-physiological signals to the system in real-time in parallel with the contextual information and have them processed in real-time as well. By providing output in real-time, the system can be utilized to perform interventions in a wide range of applications. For example:

Stress management – The proposed system could be used to measure high arousal and negative valence inducing events and enable individuals to track and address the dominant causes of stress throughout their lives by providing notifications at stressful times.

Chronic disease management – by utilizing additional sensors to gather contextual data and bio-physiological data, it may be possible to track disease progression. More importantly, the system may provide insights on which events have a negative or positive impact on the disease. For instance, eating frequently at fast food establishments (can be tracked by GPS) or ordering take-out from such places (can be tracked by call logs /web browsing) can have a negative impact on the users health: weight gain, high cholesterol levels and high blood pressure. The system may provide notifications to the user when it detects one of these events.

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Appendix A - COUHES Application

	Massachusetts Institute of Technology	Application #	
	Committee on the Use of Humans as Experimental Subjects	(assigned by COUHES)	
		Date	03/21/12

APPLICATION FOR APPROVAL TO USE HUMANS AS EXPERIMENTAL SUBJECTS (STANDARD FORM)

Please answer every question. Positive answers should be amplified with details. You must mark N/A where the question does not pertain to your application. Any incomplete application will be rejected and returned for completion. A completed **CHECKLIST FOR STANDARD APPLICATION FORM** must accompany this application.

I. BASIC INFORMATION

1. Title of Study			
Frequent EDA Event Logging: A system for collection and annotation of electrodermal activity recordings			
2. Principal Investigator			
Name: Rosalind Picard, Sc.D.		Building and Room #: E14-374G	
Title: Prof. Media Arts and Sciences		Email: picard@media.mit.edu	
Department: Media Arts and Sciences		Phone: (617)253-0611	
3. Study Personnel			
All key personnel ¹ including the PI must be listed below, with a brief statement of qualifications and study role(s).			
Important Note: all key personnel are required to complete Human Subject training before work begins on the project.			
Investigators and other personnel [and institution(s)] include email address:	Qualifications: Describe briefly	Study role(s): (Check box to the right if person will be obtaining consent.)	
Rosalind W. Picard, MIT	Sc.D.	PI	<input checked="" type="checkbox"/>
Yadid Aizenberg, MIT	MAS Graduate Student	Co-PI	<input checked="" type="checkbox"/>

¹ MIT key personnel all individuals who contribute in a substantive way to the execution and monitoring of the

web site. COUHES may accept proof of training from some other institutions. List the names of all study personnel and indicate if they have taken a human subjects training course.

Rosalind W.Picard (CITI Certified)
 Yadid Ayzenberg (CITI Certified)
 Micah Eckhardt, MIT (CITI Certified)
 Robert Morris, MIT (CITI Certified)
 Elliot Hedman, MIT (CITI Certified)
 Akane Sano, MIT (CITI Certified)
 Ehsan Hoque , MIT (CITI Certified)
 Daniel McDuff , MIT (CITI Certified)
 Javier H Rivera, MIT (CITI Certified)
 Miriam Zisook (CITI certified)

9. Anticipated Dates of Research

Start Date: 04/01/2012

Completion Date: 12/1/2016

II. STUDY INFORMATION

1. Purpose of Study. *Please provide a concise statement of the background, nature and reasons for the proposed study. Use non-technical language that can be understood by non-scientist members of COUHES.*

Wearable biosensors can play an important role in the evaluation and early detection of risk factors to reduce morbidity and mortality, measurement and communication of one's internal physiological state, as well as promotion of healthy lifestyles. By enabling comfortable and continuous assessment outside of a clinical or lab setting, not only do wearable sensors provide a clearer, in-situ picture of a person's physiological state, they also allow the monitoring of various physiological parameters at longer time scales (days to months) that could potentially reveal previously unobservable trends.

One of the greatest challenges that face researchers and individuals wishing to analyze the data is a lack of unintrusive tools for annotating the data. In order for the data to be useful it must be labeled by the individual wearing the sensor. This means maintaining a journal where the individual records his activities and experiences throughout the day. The disadvantages of this are: a) the journaling process itself alters individual behaviour and therefore affects the recorder data and b) due to the disruptive nature of the journaling process, the individual will not be able to log every activity as it occurs. The purpose of this study is to evaluate a new tool for recording the user's activities using a mobile phone and web interface. In the first stage of the study, participants will be required to record their own activities manually and in the second stage they will be required to use the new tool and report their user experience.

2. Study Protocol. *For biomedical, engineering and related research, please provide an outline of the actual experiments to be performed. Where applicable, provide a detailed description of the experimental devices or procedures to be used, detailed information on the exact dosages of drugs or chemicals to be used, total quantity of blood samples to be used, and descriptions of special diets.*

For applications in the social sciences, management and other non-biomedical disciplines please provide a detailed description of your proposed study. Where applicable, include copies of any questionnaires or standardized tests you plan to incorporate into your study. If your study involves

interviews please submit an outline indicating the types of questions you will include.

You should provide sufficient information for effective review by non-scientist members of COUHES. Define all abbreviations and use simple words. Unless justification is provided this part of the application must not exceed 5 pages.

Attaching sections of a grant application is not an acceptable substitute.

The study will involve the following experiment. The study participants will be asked to wear two commercial electrodermal activity (EDA) wrist biosensors for a period of 10 days. In addition, we will install an application on the participants mobile phones. This application will collect the following data:

- Calendar event details (start time, end time, location, etc)
- Phone call details (start time, end time, recipient)
- Email reading (start time, end time, subject, etc)
- Location

The information above will be viewable only to the participant (password protected by password of his/her choice). This is a comparative study. We intend to show that the new tool increases the data collection effectiveness and quality of data that is collected. For that purpose we plan to run the following experiment:

Stage 1 (days 1-5)

At the end of each day, the participants will upload their EDA recording files to a web site. After uploading the files the participants will be asked to view their EDA recording on a plot and asked to annotate several peaks on the plot.

Stage 2 (days 6-10)

At the end of each day, the participants will upload their EDA recording files to a web site. After uploading the files the participants will be asked to view their EDA recording on a plot as well as annotations made automatically by the system based on the collected mobile phone data. The participants will be asked to annotate several peaks on the plot.

In both stages the participants will be asked the following questions (wording is approximate and may differ very slightly in the actual study):

1. Please label this peak and describe what happened at the time
2. How stressful was this event (Likert scale)
3. How pleasurable was this event (Likert scale)
2. How clearly do you recall this event (Likert scale) alt: "I remember this event clearly"
3. Rate the accuracy of your label - (Likert scale) alt "I am certain this label is for this event"

In addition, the participants will be asked to rate the efficiency of their labeling on that day.

At the end of the study we will perform an ethnographic interview to obtain qualitative information on the usability of the new tool. We will ask participants to describe what techniques they used to remember the events they encountered throughout the day prior to using the new system and after using it.

3. Drugs and Devices. *If the study involves the administration of an investigational drug that is not approved by the Food and Drug Administration (FDA) for the use outlined in the protocol, then the principal investigator (or sponsor) must obtain an Investigational New Drug (IND) number from the FDA. If the study involves the use of an approved drug in an unapproved way the investigator (or sponsor) must submit an application for an IND number. Please attach a copy of the IND approval (new drug), or application (new use.).*

If the study involves the use of an investigational medical device and COUHES determines the device poses significant risk to human subjects, the investigator (or sponsor) must obtain an Investigational Device and Equipment (IDE) number from the FDA.

<p>Will drugs or biological agents requiring an IND be used? YES <input type="checkbox"/> NO <input checked="" type="checkbox"/> <i>If yes, please provide details:</i></p> <p>Will an investigational medical device be used? YES <input type="checkbox"/> NO <input checked="" type="checkbox"/> <i>7.1.1.1.1 If yes, please provide details:</i></p>
<p>4. Radiation <i>If the study uses radiation or radioactive materials it may also have to be approved by the Committee on Radiation Exposure to Human Subjects (COREHS). COUHES will determine if you need COREHS approval.</i></p>
<p>Will radiation or radioactive materials be used? YES <input type="checkbox"/> NO <input checked="" type="checkbox"/> <i>If yes, please provide details:</i></p>
<p>5. Diets</p>
<p>Will special diets be used? YES <input type="checkbox"/> NO <input checked="" type="checkbox"/> <i>If yes, please provide details:</i></p>

III. HUMAN SUBJECTS

1. Subjects	
A. Estimated number: 50	B. Age(s): 18-90
<p>C. Inclusion/exclusion criteria</p> <p>i. What are the criteria for inclusion or exclusion?</p> <p><i>Willingness to wear the commercially-available biosensors. Informed consent to participate. Has been using an android smart phone calendar for at least 4 weeks</i></p> <p>ii. Are any inclusion or exclusion criteria based on age, gender, or race/ethnic origin? If so, please explain and justify</p> <p>No</p>	
<p>D. Please explain the inclusion of any vulnerable population (e.g. children, cognitively impaired persons, non-English speakers, MIT students), and why that population is being studied.</p> <p>Investigators & their family members: Investigators involved in this study and members of their family may volunteer to participate in the abovementioned experiments in order to gather preliminary data in order to test the stability and usability of the system and make necessary adjustments prior to gathering data from non-investigator participants.</p> <p>MIT students will participate in order to evaluate whether various age groups and work environments affect the system evaluation.</p>	
<p>2. Subject recruitment <i>Identification and recruitment of subjects must be ethically and legally acceptable and free of coercion. Describe below what methods will be used to identify and recruit subjects</i></p> <p>Word of Mouth, E-mail and Flyers</p> <p><i>Please attach a copy of any advertisements/ notices and letters to potential subjects</i></p>	
<p>3. Subject compensation <i>Payment must be reasonable in relation to the time and trouble associated with participating in the study. It cannot constitute an undue inducement to participate</i></p> <p>Describe all plans to pay subjects in cash or other form of payment (i.e. gift certificate) Participants will be given gift certificates of up to \$130 for the full completion of the study as well as a chance to win a lottery of a \$100 gift certificate.</p> <p>Will subjects be reimbursed for travel and expenses?</p>	

N/A

4. Potential risks. *A risk is a potential harm that a reasonable person would consider important in deciding whether to participate in research. Risks can be categorized as physical, psychological, sociological, economic and legal, and include pain, stress, invasion of privacy, embarrassment or exposure of sensitive or confidential data. All potential risks and discomforts must be minimized to the greatest extent possible by using e.g. appropriate monitoring, safety devices and withdrawal of a subject if there is evidence of a specific adverse event.*

What are the risks / discomforts associated with each intervention or procedure in the study?

Long-term, daily activity monitoring: There is a risk of feeling socially awkward when wearing sensors during daily activities.

General sensor risks: Although extremely rare, there is potential for our sensors to cause mild irritation to delicate skin if there is lotion (especially sunscreen, moisturizers, oils, etc.) on the skin where the sensors are being worn.

What procedures will be in place to prevent / minimize potential risks or discomfort?

Long-term, daily activity monitoring: Participants will be told they can voluntarily remove their sensors during daily activities if it makes them feel socially awkward. Our sensor form factors, however, are designed to be inconspicuous.

General sensor risks: Verbally and in writing, participants will be asked to avoid using lotions on areas where our sensors make contact with skin. If lotion has been applied, they will be asked to wipe the area clean with alcohol on a cotton ball or wipe firmly with a wet (water only) washcloth or towel until the skin feels clean and free of any oil before using the sensors. We will also ask repeatedly about sensor comfort and any signs of skin irritation. If any irritation arises when using our sensors, we will instruct participants to discontinue their use. We will also report any adverse reactions to COUHES.

5. Potential benefits

What potential benefits may subjects receive from participating in the study?

Participants may enjoy learning about things that cause their autonomic arousal to change, and contributing to future technology.

What potential benefits can society expect from the study?

It is our hope that such a tool will provide individuals with a better journaling experience and researchers with a tool to collect high quality annotations

6. Data collection, storage, and confidentiality

How will data be collected?

Sensor Data - Physiological signal measurements will either be recorded onto micro-SD cards or wirelessly transmitted to a radio receiver that is part of a computer or personal digital assistant. All data will be time stamped and tagged with a sensor number. We will give participants code numbers and keep their identifying information separate from the data and its annotations.

Is there audio or videotaping? YES NO *Explain the procedures you plan to follow.*

Will data be associated with personal identifiers or will it be coded?

Personal identifiers Coded *Explain the procedures you plan to follow.*

Each participant will be assigned a participant code and their data will be associated with this code number. All data with identifying information will be stored on password-protected computers in the Media Lab. Data being analyzed will be identified by participant codes and identifying information will be removed. Identity of participants will not be revealed in the presentation or publication of any results from the project. Assistants and others working on the project will be educated about the importance of strictly respecting the participants' right to confidentiality.

Where will the data be stored and how will it be secured?

On password-protected computers in the Media Lab.

What will happen to the data when the study is completed?

It will be stored in a secure, "permanent" archive for as long as the data is useful for research and system development. After it's usefulness has passed, it will be destroyed.

Can data acquired in the study affect a subject's relationship with other individuals (e.g. employee-supervisor, patient-physician, student-teacher, family relationships)?

No. Participation in this study is entirely voluntary, all data collected will be deidentified, and only investigators involved in the study will have access to the data.

7. Deception *Investigators must not exclude information from a subject that a reasonable person would want to know in deciding whether to participate in a study.*

Will information about the research purpose and design be withheld from subjects?

YES NO *If so, explain and justify.*

8. Adverse effects. *Serious or unexpected adverse reactions or injuries must be reported to COUHES within 48 hours. Other adverse events should be reported within 10 working days.*

What follow-up efforts will be made to detect any harm to subjects and how will COUHES be kept informed?

We will give participants our phone numbers and contact information and make it clear that we are happy to be contacted with any questions or concerns that may arise. We will also notify COUHES immediately if any problems are reported.

9. Informed consent. *Documented informed consent must be obtained from all participants in studies that involve human subjects. You must use the templates available on the COUHES web-site to prepare these forms. Draft informed consent forms must be returned with this application. Under certain circumstances COUHES may waive the requirement for informed consent.*

Attach informed consent forms with this application.

10. The HIPAA Privacy Rule. *If your study involves disclosing identifiable health information about a subject outside of M.I.T., then you must conform to the HIPAA Privacy Rule and complete the questions below. Please refer to the HIPAA section, and to the definitions of protected health information, de-identified data and limited data set on the COUHES web-site.*

Do you plan to use or disclose identifiable health information outside M.I.T.?

YES NO

If YES, then the subject must complete an Authorization for Release of Protected Health Information Form. Please attach a copy of this draft form. You must use the template available on the COUHES web-site.

Alternatively, COUHES may grant a Waiver of Authorization if the disclosure meets criteria outlined on the COUHES web-site.

Are you requesting a Waiver of Authorization?

YES NO

If YES, explain and justify.

Will the health information you plan to use or disclose be de-identified?

YES NO

Will you be using or disclosing a limited data set?

YES NO

If YES, then COUHES will send you a formal data use agreement that you must complete in order for your application to be approved

IV. Investigator's Assurance

I certify the information provided in this application is complete and correct

I understand that I have ultimate responsibility for the conduct of the study, the ethical performance of the project, the protection of the rights and welfare of human subjects and strict adherence to any stipulations imposed by COUHES

I agree to comply with all MIT policies, as well all federal, state and local laws on the protection of human subjects in research, including:

- **ensuring all study personnel satisfactorily complete human subjects training**
- **performing the study according to the approved protocol**
- **implementing no changes in the approved study without COUHES approval**
- **obtaining informed consent from subjects using only the currently approved consent form**
- **protecting identifiable health information in accord with the HIPAA Privacy Rule**
- **promptly reporting significant or untoward adverse effects**

Signature of Principal Investigator _____ Date _____

Print Full Name and Title _____

Signature of Department Head _____ Date _____

Print Full Name and Title _____

Please return 3 hard copies of this application (1 with original signatures) to the COUHES office E25-143b.

Appendix B - Participant Consent Form

Measuring the effectiveness of a system for collection and annotation of electrodermal activity recordings

You are asked to participate in a research project with the researchers at the Massachusetts Institute of Technology (MIT) Media Laboratory. You should read the information below and ask questions about anything you do not understand before deciding whether or not to participate.

PARTICIPATION AND WITHDRAWAL

Your participation in this study is completely voluntary, and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw at any time without penalty or consequences of any kind. The investigator may also withdraw you from this research if circumstances arise which warrant doing so.

PURPOSE OF THE STUDY

This study will explore if mobile phone applications can collect data on every day experiences and whether that data can be used to better understand recordings from physiological sensors.

The physiological sensors are non-invasive measurement devices that are worn on the wrist (similar to a watch). The sensors records skin temperature, movement, and conductance of the skin.

The skin conductance goes up when you sweat, but also can change even when you don't feel any sweat on the surface of the skin. Changes in the level of conductance are used to measure a person's stress, excitement, anxiety and arousal.

PROCEDURES

If you volunteer to participate in this study, here is what will happen:

An application will be installed on your smartphone. This application will record the following:

- The start and end time of your phone calls and the other caller's phone number
- The start and end time of each of your calendar items, and the item subject, location and attendee names
- As you read emails, the application will record the start and end time of each email you read as well as the subject, sender, and recipients.

We will ask you to wear two wristband sensors during 10 days. During these 10 days, you should charge the sensor for at least 1 hour per day, which should suffice for 18 hours of activity. It is strongly recommended that you wear the sensors during sleep as well. Before starting the study you will be asked to fill in a short on-line survey. During each day of the study days you will be required to upload your sensor data at the end of the day via the Internet and fill in an additional short survey online. At the end of the study we will conduct an interview with you.

POTENTIAL RISKS AND DISCOMFORTS

It is possible that anybody who wears these sensors will experience mild skin irritation, itching, or other discomfort when the sensor contacts the skin. If any discomfort is reported or observed, we will ask you to remove the sensors. We want to make sure that nobody feels pressured to wear them.

It is also rare but possible to experience temporary discoloration of the skin under on or both metal electrodes. This should not be harmful and should go away within 2 to 14 days.

POTENTIAL BENEFITS

The information collected in this study may help researchers develop and deploy better tools for annotation of long term physiological signal recordings.

PAYMENT FOR PARTICIPATION

You will be given \$130 Target or Amazon gift certificates (or a combination of your choice) after the full completion of the study surveys and wearing the sensors for the entire duration of the study.

In addition, if you complete the full study you will be eligible to enter a lottery for an additional \$100 gift certificate.

CONFIDENTIALITY

This data will be used for experimental purposes and will be archived in a password protected, secure network at the Media Lab. Each recording will be associated with a random id number. The association between your name and id will be stored on a different machine. You will be able to access your data by using a password that will be chosen by you. This password will be encrypted and stored in the database and cannot be retrieved by anyone but you.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

Upon the conclusion of the study, only event times, durations and sensor recordings will be retained. All other personal information will be deleted from the database.

Portions of this record may be published and/or presented in scientific journals and/or in scientific conference proceedings. Further, no information, such as name, address, or other private information will be included in these presentations or publications apart from what is mentioned in the interview. Apart from this possible usage, such data will only be viewed/used for research and educational purposes. At any time during or after the study you may request to review or edit your recorded information and request that it be deleted.

It is possible that there will be other uses for the data in the future. You will be given a separate option below to allow for this possible broader sharing and usage of the data.

IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact, Dr. Rosalind Picard, Principal Investigator (617)253-0611 or Yadid Ayzenberg (yadid@mit.edu), Co-Principal Investigator (617)866-7226.

EMERGENCY CARE AND COMPENSATION FOR INJURY

If you feel you have suffered an injury, which may include emotional trauma, as a result of participating in this study, please contact the person in charge of the study as soon as possible. In the event you suffer such an injury, M.I.T. may provide itself, or arrange for the provision of, emergency transport or medical treatment, including emergency treatment and follow-up care, as needed, or reimbursement

for such medical services. M.I.T. does not provide any other form of compensation for injury. In any case, neither the offer to provide medical assistance, nor the actual provision of medical services shall be considered an admission of fault or acceptance of liability. Questions regarding this policy may be directed to MIT's Insurance Office, (617) 253-2823. Your insurance carrier may be billed for the cost of emergency transport or medical treatment, if such services are determined not to be directly related to your participation in this study.

RIGHTS OF RESEARCH PARTICIPANTS

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Name

Signature of Subject

Date

OPTIONAL ADDITIONAL SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I agree to have my skin conductance, and surveys used not only for the scientific research described above, but also for my data to be shared with other scientific researchers outside of MIT. I also give permission for this data to be used for educational and media purposes. I realize if I give permission, that the skin conductance, may be used on public websites and videos designed to show the usefulness of the sensors and research methodology. Identifying information (name, address, etc.) of participants will not be disclosed.

Name

Signature of Subject

Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

Signature of Investigator

Date

Appendix C - System Usability Scale (SUS)

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
2. I found the system unnecessarily complex	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
3. I thought the system was easy to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
5. I found the various functions in this system were well integrated	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
6. I thought there was too much inconsistency in this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
8. I found the system very cumbersome to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
9. I felt very confident using the system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	1	2	3	4	5

Using SUS

The SU scale is generally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. Respondents should be asked to record their immediate response to each item, rather than thinking about items for a long time.

All items should be checked. If a respondent feels that they cannot respond to a particular item, they should mark the centre point of the scale.

Scoring SUS

SUS yields a single number representing a composite measure of the overall usability of the system being studied. Note that scores for individual items are not meaningful on their own.

To calculate the SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1,3,5,7, and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU.

SUS scores have a range of 0 to 100.

The following section gives an example of a scored SU scale.

Appendix D - Ethnological Survey Questionnaire

Note: These questions refer to the Web Interface Software only (and not the Hardware sensor).

User Experience Survey

1. This application is fun to use

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

2. I would recommend this application to my friend

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

3. I prefer maintaining my own journal for recording context

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

4. I think FEEL is more reliable than maintaining my own journal

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

5. I would use this application regularly

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

6. The data collected with FEEL has provided me with insights regarding my responses to events

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

7. I really like having the possibility to view the contextual data along with the EDA

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

8. The sensors were comfortable to wear

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

9. The Mobile Application was non intrusive and did not require any attention

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

Disagree		Disagree		Agree		Agree

10. What is the your least favorite thing about this application?
11. What do you think is lacking in the application?
12. What do you think is the best thing about this application?
13. Would you like to give any suggestion for changes or improvement?
14. What is the best thing about maintaining your own journal?
15. What is your least favorite part about maintaining your own journal?
16. Describe what techniques you used to remember the events you encountered throughout the day when you used the non-contextual interface
17. What elements in the system were most useful to you for recalling the events (calendar, email, location, etc.)?

Appendix E - Event Self Report Questions

The valence and arousal diagrams in the event user report are based on [44]

Event User Report










All form fields are required.

Please describe what occurred approximately at 20:06

Rate the accuracy of your label

1 ○ ○ ○ ○ ○ ○ ○ 7

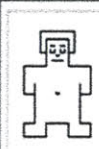
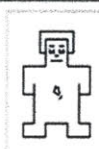
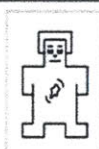


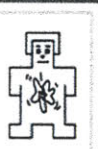



What was your Valence (Negative vs Positive)

								
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How confident are you in your above rating for Valence?

1 ○ ○ ○ ○ ○ ○ ○ 7

What was your Arousal (Calm vs Excited)

								
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How confident are you in your above rating for Arousal?

1 7

How clearly do you recall what happened at that time

Not clear at all Extremely clear

Any additional information you would like to note: