Wireless mobile technology in physiological signal processing

Physiology as an asset for security

Pedro Miguel Ferreira¹, Eurico Carrapatoso²

¹,²Faculty of Engineering of the University of Porto
Rua Dr. Roberto Frias, s/n 4200-465 Porto PORTUGAL,
¹pro11021@fe.up.pt

Abstract. Any given human body generates electrical signals, known as physiological signals, which, by their nature, can be collected, transmitted, stored and interpreted in order to, among other purposes, assess state of emotion. This paper presents a system, tailored to validate wireless physiological signal transmission and processing feasibility, based on low budget wireless mobile equipment for a fight-or-flight response detection using artificial neural networks. The system was built on current theoretical knowledge on psychophysiology, regarding heart rate, in fight-or-flight emotional response. The system has not been tested on human subjects but still was found feasible with natural but undetermined constraints on power consumption related to wireless communication.

Keywords: Affective Computing, Physiological Signals, Artificial Neural Networks, Wearables, Real-Time Systems.

1 Introduction

Affective Computing is a relatively novel field of research that seeks to understand interaction of humans with computer systems. Some Affective Computer workgroups are committed to dim the line between computer systems and humans, thus making interaction as transparent as possible, whilst other groups are devoted to giving machines the ability to feel and reason. Understanding how emotions work, how they affect the human body and, in the end, if emotions are differentiable considering only physiological signals space is essential. For the moment there are a handful of theories and models for human emotion: somatic theories; neurobiological theories; cognitive theories; other theories. Nevertheless there is common ground between the theories.

Some Affective Computing investigators have been devoted to building wearables [23] which are usually an assortment of sensors and signal processing unit or units. These wearables have been put to use in many distinct scenarios such as collecting the user’s physiological signals, to log or process them, in order to make changes in com-
puter system interface or even allow multimedia emotional interactive systems. This study is based on a research [17] on wearable for driver stress assessment. The baseline for the work described in this paper is that physiological changes occur, in heart rate, whenever fear arises as elicited emotion and that there is current market mobile equipment that may be used to build a wearable person based security system. Current handheld equipment allows wireless communication on Bluetooth technology and wireless internet/intranet access which are fundamental to connect to wireless sensors and to access internet/intranet based databases and services.

To test the effectiveness of the proposal a computer application was implemented, on J2ME mobile platform, which receives, processes, stores and performs automated evaluation of physiological cardiac signal in search for evidence of fight-or-flight emotional state.

2 Background and previous work

One of human basic needs, as stated by Maslow\(^1\), is the need for security. Every healthy human being feels the need to maintain and preserve body integrity. This fundamental need is at risk on account of basic factors like: society’s heterogeneity; individual moral evolution diversity; inequality of opportunities. And in times of economic crisis, such as the one currently settled, a social crisis usually follows, crime occurrences raise which, in turn, lowers society perception of security.

Existing security systems are mainly based on human intentional alarm activation. These systems fail on principle because intentional alarm activation, in situations such as the attempt to take a valuable object by force, or threat of force, usually puts the victim in state of fear. Self-preservation sense will be overwhelming, for untrained individuals, to the point that alarm activation will be the least of worries. The disabling condition, fight-or-flight response, may be key factor in developing personal tailored alarm systems which do not depend on will power for activation.

2.1 Emotion

Psychophysiology

The human body is endowed with a complex communication and control network, called Nervous System (SN), which allows proper interaction with both internal (body and its subsystems) and external environments (the world outside the body) [2]. The nervous system includes: sensors – to perceive events from the environment; integrators - to process and store data; components and engines that generate behavior and activate gland secretions. Organized by parts or layers, the nervous system is divided into two main components: the central nervous system (CNS) and Peripheral Nervous System (PNS) [2]. The CNS, comprising the brain and spinal cord, is responsible for, among other functions, cognition, memory and learning, reflex responses and behavioral responses. Learning and memory are forms of information processing that al-

\(^1\)Maslow's hierarchy of needs was proposed by Abraham Maslow in his 1943: http://en.wikipedia.org/wiki/Maslow's_hierarchy_of_needs, visited 2-Jan-2012.
low changes in behavior or state, based on previous experiences, in order to cope with environment demands. Many of the activities of the body such as breathing, heartbeat and digestion take place without conscious intervention. One function of the autonomic nervous system (ANS) is maintaining the internal state of the body to achieve homeostasis. This sub-system of the nervous system participates in determining appropriate and coordinated response to environmental stimuli. The response to presence or perception of a threat is massive. Sympathetic nervous subsystem forces the secretion of the adrenal gland, increases heart rate and blood pressure, dilates the bronchioles, inhibits intestinal motility, increases the metabolism of glucose, dilates the pupils, promotes piloerection and forces dilation of blood vessels of skeletal muscles. This is the response, to intense fear or panic, known as fight-or-flight.

Emotion and psychophysiology

Studies have shown that emotions are related to increased activity in certain brain areas, more specifically in the areas of the limbic system [8]. This system is formed by the hypothalamus, the hippocampus, located in the temporal lobe, and the amygdala. It is well known, and accepted, that this system is responsible for characterization of emotional events labeling them as positive or negative [8]. The limbic system, which contributes for flexibility and unpredictability in human behavior, has connections with the cerebral cortex. The brain is considered to be the result of two systems, limbic and cortex, which interact and function as a black box processing the inputs and generating the correspondent outputs [8]. For the neuroscientist Antonio Damasio [24], primary emotions are innate and quick reactions and correspond to emotions of fear, surprise and anger. This author also states that the essence of emotion can be seen as the set of changes in body state and that these changes have repercussions in various organs. This dedicated system responds to thoughts directed to a particular entity or event. Some body's status changes - for instance body posture and facial expression - are visible to outside observers. Other changes are only noticeable to the owner of the body. This neuroscientist also states that the emotion "is the combination of a mental evaluation process, simple or complex, with dispositional responses to that process, mostly directed at the body itself, resulting in an emotional state of the body, but also addresses the very brain (neurotransmitter nuclei in the brainstem), resulting in additional mental changes (...)"[24].

Any given organism will perceive an internal or external stimulus in his own way, eventually distinct from any other, and any given organism may perceive identical stimulus with different degrees of intensity in different days. Any given subject’s biological internal state affects His mental state and vice-versa. Every subject is the result of a tendency toward internal equilibrium (homeostasis) which depends on current internal state and current environmental stimuli.

In scientific literature there is no conclusive connection between any current theory of emotion and a set or sets of physiological signals. There is still a too high inter and intra subject variability. The system and algorithm depicted in this paper are, to some extent, empirical and based on the fact that physiological changes do happen. These changes may they be in response to environmental or internal stimuli, thus generating emotion, or may be in response to an emotion, thus somatizing it, generating corres-
ponding physiological changes. In any of the theories it is common that in a fight-or-flight response physiological changes occur and, among those changes, heart rate usually rises in abrupt way like in an effort scenario.

### 2.2 Related work

One of the works in Affective Computing, related to this paper, was implemented by Jennifer Healey [17] in which it presented study and set of experiences to investigate the correlation between physiological signals and physical activities like walking, running or coughing.

![Fig. 1. Physiological signals during specific activities [17]](image1)

In previous figure, figure 1, it may be noted that the more reactive indicator is heart rate (HR). Heart rate follows activity changes, increasing or decreasing in excitement or relaxation. Figure 2, bellow, depicts a set of studies and their findings on how fear and sadness affect heart rate. Not all studies present the same effects.

![Fig. 2. Effect of fear and sadness on heart rate [18]](image2)
Another related work is “The Mobile Patient and the Mobile Physician Data Access and Transmission” [3]. That paper describes a system composed of a wearable device - VivoMetrics LifeShirt®, a Personal Digital Assistant (PDA) and internet connection to a base station (server). In this project the wearable records physiological signals with submission done later through PDA or desktop computer. The wearable has the ability to send data, via Bluetooth, but does not process data.

2.3 Automated emotion recognition

Processing physiological signals has been one of the approaches, with varying degrees of success, in mapping signals space to emotional state space [8]. If there is a correlation between physiological signals and emotional state, of any given organism, we can say it is a privileged way to recognize the relationship between man and the environment. These signals can become, progressively, elements of characterization, classification and prediction of an individual’s emotional state.

The most effective methods and, therefore, more used methods in automated emotion recognition are support vector machines (SVM) and artificial neural networks (ANN). For this work ANN with preprocessing of data was chosen for the classification.

Artificial neural networks (ANN).

An artificial neural network (ANN) is a paradigm of data processing based on the structure and organizational model of the human brain. An ANN is a set of artificial neurons, with weights associated with each connection (input), and depending on the combination of activation function of the neuron with the weighted sum of inputs it produces an output. The ANN can perform learning by modifying its parameters including the weight and value of activation. The ANN is specialized in a particular subject and often used in activities of classification and pattern recognition. ANN presents favorable results and good tolerance to lack or failure of input values. The concept of artificial neuron was created by Warren McCulloch and Walter Pitts [8]. The weights (W) associated with each input connection (X) are determined in learning stage. The bias, not mandatory, is the activation limit for the neuron. An activation function is applied to the computation of the weighted sum of inputs.

![Generic neuron in ANN](image_url)
3 Proposed framework and method

The developed system consists of three distinct modules: the PDA - collects and processes physiological signals (client); module for processing requests for service and storage of physiological signals in a database (local server); virtual emulated ECG sensor module.

3.1 ECG Data

To study physiological signals and correlations, some sets of records, found at Physionet, MIT (physionet.org), were used. This service provides several online databases of physiological trustworthy signals extracted from multiple individuals. Among them are the data sets made available by Jennifer Healey [17] during an investigation on stress in drivers. These data sets are multiparameter records (ECG, GSR, Respiratory rate and BVP), of healthy volunteers, obtained in regular office activities and during driving in the city of Boston.

3.2 Framework

Building a wireless and mobile personal security system, able to perform physiological signal transmission and processing, based on wireless low budget technology, requires equipment such as: handheld Smartphone or PDA; wireless ECG sensor; computer acting as server for stored data (database). To assess feasibility of this current proposal we chose to emulate these equipments. The compromise solution was built on Sun’s Java Wireless toolkit which allows emulation of smartphone with Bluetooth and wifi capabilities. The ECG sensor was also virtualized using the same toolkit. The virtual ECG sensor was built on the same principles of current marketed solutions and displays/sends integer values as current subject’s heart rate. On account of data to be transferred, between the ECG sensor and the handheld equipment, being simple integer values makes this virtualization as plausible as any real setting environment. No problems were expected regarding data transfers, in what comes to transmission delays, which could impair the emulated systems approach.

Fig. 4. Proposed Framework

In this projected framework the ECG sensor is responsible for sending, every 2 seconds, a numerical integer value (heart rate). Values will be received by the PDA/handheld equipment. The PDA will perform necessary preprocessing of data collected and feed the results to the ANN. Preprocessing simplifies data and eases ANN workload in performing the classification of emotion state according to previous
learning. Any generated “stress” alarms will also be recorded in a database table. Figures 5 and 6 depict aspects of the Sun’s Java Wireless toolkit emulated equipment. Reference heart rate can be raised or lowered by pressing keys 2 or 1, respectively.

Fig. 5. Emulated handheld/PDA

Fig. 6. Emulated ECG sensor

3.3 Algorithm

The algorithm that pre-processes heart rate data employs the concept of heart rate effort [15]. This effort was determined by dividing the instantaneous heart rate by the estimated maximum upper limit (see table 1). At the Portuguese Foundation of Cardiology (PFC) web page can see that rates above 75% of maximum heart rate frequency can be considered excessive for untrained subjects and that the reference heart rate, during exercise, is between 60% and 75% of maximum heart rate. Maximum frequency depends on age and can be defined, though not the most accurate formula, as the constant 220 minus age in years (see table 1).

<table>
<thead>
<tr>
<th>Age</th>
<th>Reasonable effort heart rate Limits</th>
<th>Maximum heart rate</th>
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<tbody>
<tr>
<td>20</td>
<td>120-150/mans</td>
<td>200/mans</td>
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<td>25</td>
<td>115-140/mans</td>
<td>195/mans</td>
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<td>30</td>
<td>110-142/mans</td>
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<td>35</td>
<td>106-138/mans</td>
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<td>102-131/mans</td>
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<td>45</td>
<td>98-127/mans</td>
<td>175/mans</td>
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<td>50</td>
<td>94-122/mans</td>
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<td>70</td>
<td>78-132/mans</td>
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Table 1. Reference heart rate by age [15]

The solution found to analyze ECG was implemented on artificial neural network with a preprocessing algorithm for cardiac signal. The ANN has 10 neurons in the
first layer, 7 in the hidden layer and 1 in the output layer. The activation function is
the standard sigmoid (logistic). The handheld system and software must load all ar-
tificial neural network parameters, previously defined, stored in a database. It also
records, throughout the day, cardiac signal values. This behavior keeps the system up
to date in what comes to the natural and evolving state of the subject which can vary
throughout life. The implemented algorithm relies on a sliding window. This ap-
proach helps to overcome variability in very close readings. Still it is considered as
real time architecture despite physiological signal is read in a constant discrete-time.
Any computer system is necessarily discrete. The data received from the virtual ECG
sensor, which simulates the physiological signal sensor, running on Sun’s Java wire-
less toolkit emulator, is integrated in a sliding window of size 10. The window con-
tains the last 10 numerical values of heart rate. The determination of the emotional
state of fear is realized by artificial neural network starting from the suppositions and
knowledge on psychophysiological reaction fight-or-flight already stated.

Some numerical constants are found in the algorithm. They are an empirical ap-
proach and should be subject of further study. The use of sliding windows dims the
probability of occurrence for false positives because singularities, errors or short dur-
ation startles, shall have diluted effect.

The preprocessing algorithm acts under the following specifications:

— When a user logs on successfully 10 units of heart rate will fill the "sliding win-
dow" of attention;
  • While the window is being filled will calculate:
    ○ Average (current in window values and previous homologous work period
      average);
    ○ Standard deviation (in window values);
  • The first value available in the “sliding window” is the homologous period av-
erage stored in the database.
— After filling the window the assessments for emotional state can be held calculat-
ing:
  • Window Average;
  • Window Standard deviation (Std);
  • Std Jitter (numerical difference between current calculated Std and the previous
    Std);
  • Window average jitter
    ○ numerical difference between current calculated window average and the
      previous;
  • Instantaneous Effort rate (Rest)
    ○ instantaneous value obtained from the sensor divided by the average of re-
cording at rest condition;
  • Instantaneous Effort rate (working)
    ○ instantaneous value obtained from the sensor and divided by the average of
    recording at working condition;
  • numerical difference between the instantaneous value and the average recorded
    for the same period (dif1);
• Variation of the previous value (Dif1) to Std of the same work period
  \((\text{Dif1}/\text{desvpPerHomol}) \rightarrow (\text{VAR1});\)
• Assess the rate of stress to the average at rest
  \(\circ\) If equal or greater than 1.4 times the average value obtained at rest then it
  creates an alarm (AL1 = 1);
• Assess the rate of stress compared to the average at work
  \(\circ\) If equal or greater than 1.25 times the average value obtained at work then it
  creates an alarm (AL2 = 1);
• Evaluate the difference between instantaneous value
  \(\circ\) If greater than 0 then create alarm (AL4 = 1)
• Verify if windows average has risen
  \(\circ\) If affirmative create alarm (AL5 = 1);
• Assess whether the instantaneous value is lower than the average recorded at
  rest subtracted from the corresponding standard deviation at rest
  \(\circ\) If true then create alarm (AL6 = 1);
  \(\circ\) No one should have a working heart rate lower than the resting heart rate
  subtracted of the Std at rest.

The previous protocol allows the creation of different alarms (AL1 to AL6) which
will be integrated into an alarm sliding window with 10 slots. This is the “stress”
window. Alarms 7 and 8 will be determined according to following rules:

— Determine the average window of alarm AL6
  • Higher than 0.5 indicates low heart rate or disconnection without logout
    (AL7 = 1);
— Determine the average window alarms [AL1 to AL5]
  • Higher than 0.5 indicates shortage of data or actual stress tension (AL8 = 1);

All values AL1 to AL9 are fed to the ANN. The following table, table 2, presents
the all conditions under which a “stress alarm” will be generated (saida = 1).

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<th>AL1</th>
<th>AL2</th>
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Table 2. ANN input/output matrix. Inputs: (AL1 – AL9); output (saida)
4 Results

Regarding the outcome of the created software, claims can be made that the preprocessing algorithm performs the appropriate processing, in accordance with the programmed rules. The artificial neural network performs calculations, without error, in accordance with assigned values for each input connections and for each neuron. The activation function, equal for all active artificial neurons, worked as expected and results are traceable. The preprocessing algorithm reduces all integers or real values to Boolean which, in turn are fed to the ANN. Alarms are generated and recorded in the database through requests made to the local Web server. The virtual sensor allows variation of the value placed on the output through emulator’s virtual keyboard.

Coherent classification, of fight-or-flight response, was observed in PDA software. With undetermined efficiency, the PDA software algorithm and ANN classification method mapped ECG values to the corresponding and expected emotion. Whenever ECG value was consistently high, with a heart rate effort equal to or greater than 60% of maximum heart rate - recorded in the database for each employee - a stress alarm is generated. Similarly if the heart rate remains consistently below the resting ECG value, subtracted of the standard deviation, a “disconnected alarm” is generated. For this purpose a very low value of 10 beats per second was used.

5 Conclusions

The proposal of using off-the-shelf technology to enhance security of people was found feasible. There is available and mature enough technology to transmit, process and record physiological signals as described in above sections. Moreover, the tests and technical grounds used, within this approach, suggest that using minimally or non-invasive wireless sensors in conjunction with mobile devices to collect, analyze and record physiological data, in regular activity in the workplace, is both possible and desirable. The wireless solution eliminates mobility constraints and will be worthy for scenarios where one or more employees are exposed, to some extent, to security threats. Such scenarios include Taxi drivers, money transport trucks, flight stewards and any public access offices like jewellery shops, gas stations and others.

The presented algorithm has the advantage of analyzing values, read by sensor, in relating them to values recorded for each subject. It presents, in theory, high interpersonal stability. The preprocessing algorithm presents fair to good user undependability. Each subject, after being submitted to ECG studying at rest and at regular work, has a recorded base line (mean and standard deviation for ECG).

Of the examples, presented in background and previous work section, it is credible that all the necessary technologies are mature enough to produce a technological solution for personal security. Nevertheless false positives, in fight-or-flight classification, may occur out of classification error, ANN training deficiencies, or unexpected but not threatening scenarios.
6 Future work

Although the algorithm looks promising in dimming false positive occurrence, on account of sliding window, testing it with real equipment is essential to validate the system. Experimenting in controlled and uncontrolled environments to gather data and cross reference will be required.

Validation of empirical values used is also necessary. Exploitation of new equipment, like VitalJacket, may prove worthy despite it is a medical graded equipment and, therefore, more expensive. Sliding window size is also empirical and, therefore, should be submitted to further study.

The algorithm should be tested with SVM, method referred as high in efficiency and accuracy, with and without pre-processing.

Integration of more physiological signals, galvanic skin response, respiration rate and volume, could prove worthy for classification accuracy purposes. Current open source Android devices and Arduino, an open source hardware platform, will enable multiple sensor integration without mobility loss.

References

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Information obtained from Biodevices website, http://www.biodevices.pt, visited 02-01-2012


