Linguistic summarization of the human activity using skin conductivity and accelerometers

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Abstract

This paper addresses the problem of human activity monitoring including data about the degree of accumulated mental stress. We describe a simple experiment aimed at exploring the possibilities of providing people with linguistic feedback of the temporal evolution of their stress and concentration capability during the working day. We provide details about the utilized sensors and describe how to use fuzzy logic and a finite states machine to create a linguistic model of the evolution of these parameters with the time. Some experimental results are included.

Keywords: fuzzy logic, affective computing, linguistic summarization.

1 Introduction

Human activity monitoring is a field of research that has an important number of applications related with, e.g., security, safety, elderly care, human performance analysis and human computer interfaces. For monitoring human postures and movements the current research is based on video signal treatment and also on wearable sensors [1]. This work follows this second approach.

Human beings use the computers as a tool for complementing their capability for managing information. The ultimate goal consists in developing the symbiotic human – computer, taking advantage of the computers performance for memory and data processing and leaving for humans the creativity and the high level motivations [7]. A possibility of improving this symbiosis is extending the human computer interface allowing computers to acquire data about low levels of self-control of the human behaviour. This will allow humans to be assisted even when they are not conscious of their needs. It has already been demonstrated that the measurement of physiological parameters, e.g. heart rate, blood pressure, breathing and skin conductivity, can provide information about different affective states [10].

According to Antonio Damasio human beings control their behaviour using a controller aimed at increasing satisfaction and reducing suffering during the changing circumstances of their life. In words of this researcher: "Feelings of pain and pleasure or some quality in between are the bedrock of our minds" [3]. Based on this simple principle, Natural Evolution has, step by step, built a distributed control system aggregating with time different levels of functionality:

- The primitive level, located in the inner part of the brain, is dedicated to immune responses, basic reflexes and metabolic regulation.
- On top of this, levels of control exist related with pain and pleasure behaviours.
- Then a control based on drives and motivations.
- Then systems of control based on emotions and feelings.

See in [3] an introduction to these topics, including a description and localization of specific brain functions.

On the top of this hierarchy, in the most external part of the brain, sophisticated functions reside that we use consciously to control our behaviour

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allowing us to create the sophisticated mental objects that correspond with the current cultural development of humankind [13]. The overall control is built with all these levels closely interrelated forming a continuum of functionality with a high degree of complexity.

This paper addresses the possibility of using a computational system for assisting a person in specific circumstances helping him/her to monitor his/her physical and mental activity. This functionality can be useful in the case of rehabilitation treatments, anti-stress treatments or for learning good work habits.

Affective Computing is a complex field in the early stages of development. An important problem is that, in general, it is not possible to establish a direct relation between the physical parameter values obtained with sensors and the current affective state. Damasio poetically describes the complexity of human feelings in the following paragraph: "…feelings of myriad emotions and related states, the continuous musical line of our minds, the unstoppable humming of the most universal melodies that only dies down when we go to sleep, a humming that turns into all-out singing when we are occupied by joy, or a mournful requiem when sorrow takes over".

In order to reduce the complexity of the research, it is needed to work within a limited experimental realm. A good example is the study of the process of driving an automobile where the driver has a reduced number of possible perceptions and actions and the model has a limited number of situations to identify. The already available results in this field show how stress, anger and fear, provoke reactions in the driver influencing his behaviour, sometimes with dramatic consequences [8] [2] [5]. These works have the ultimate goal of monitoring the driver reactions, detecting dangerous situations, and providing some feedback that will help to improve the driver effectiveness and safety.

In a preliminary work we have used accelerometers attached to the automobile and fuzzy logic to obtain a linguistic description of the way of driving [11].

In this work we have performed the experimentation in the setting of the daily routine of a person dedicated to sedentary administrative work: reading, writing and managing a computer in an office environment. A typical situation that we wish to model could be the following:

1. The subject starts his/her day relaxed at the desk.
2. The subject turns on the computer, reads and answers emails, reads papers, writes notes and so.
3. Initially the subject will remain seated and tension levels rise slowly.
4. After time the tension starts to provoke difficulties in concentration. The subject starts moving in his/her chair and shows behaviour such as going to the toilet or moving paperwork around the office.
5. Then the subject decides to take a small walk outside 'to clear his/her mind'.
6. Finally the subject returns to his/her office desk and continues working, again in a less stressful state (similar to the starting point).

Figure 1 shows a diagram that represents the evolution of the activity and state of the subject during the experiment. Note that we consider that the subject can recover part of the initial 'relaxed state' by doing some physical exercise.

The goal consists of monitoring the physical activity, the levels of stress and mental tiredness of the subject and to create a linguistic report about the temporal evolution of these parameters. We explore the possibilities of developing a computational system where the obtained information from the sensors can be used to give feedback to the user helping the user to increase his/her effectiveness and satisfaction.

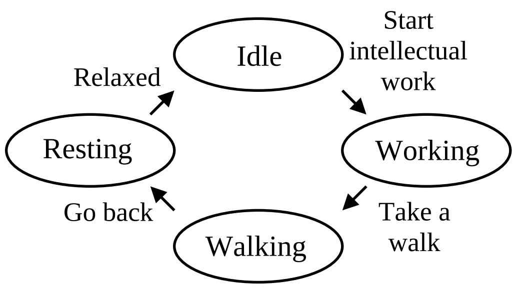

Figure 1: States model.

In the following, section 2 describes the physiological parameters and the used sensors; section 3 describes how to create a linguistic model of the system evolution using fuzzy logic and a finite states machine; section 4 describes the realized experiment and section 5 contains some conclusions and future work.

2 Equipment and measures

2.1 Accelerometers

We use accelerometers to capture the movements of the body as a measure of human physical activity. We use an electronic module, the Witilt v2.5 provided by Sparkfun Electronics, that contains a tri-axial accelerometer and that has the possibility to be operated using a BlueTooth connexion.

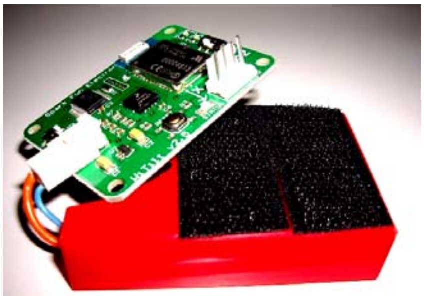

Figure 2: Tri-axial accelerometer sensor

This module, together with a slim NiMH battery, is put into a small box that is easily attached to, for example, the subject belt. This module is connected to a PDA using Bluetooth, allowing us to record the data of experiments.

The data provided by this sensor consists of an acceleration vector with three components (a_x, a_y, a_z). These values are provided in gravity units (g) in the range of [-4g, 4g] encoded with 10 bits and captured with a sampling rate of 100 Hz. In a previous work we have used this sensor to make a linguistic description of the subject body postures [12]. Figure 2 shows a photo of the sensor and its box. Figure 3 shows an example of the three signals obtained from it when the subject stands up from his chair having the sensor into the shirt pocket.

We have used the acceleration vector to define a measure of the subject physical activity given in watts. The modulus is determined directly from the values obtained by the three orthogonal accelerometers:

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

We calculate the physical activity as:

$$Activity = Force \times Velocity = a \times \int_{-\Delta T}^{\Delta T} a(t)dt$$

2.2 Skin conductivity

Human skin has an electrical resistance that varies for different reasons. It has been demonstrated that this value fluctuates quickly during mental, physical and emotional arousal.

In Affective Computing this parameter is used as information for detecting changes in the affective state. Because it is not easy to identify the cause of a change in skin conductivity and because the response is different for different individuals this sensor value must be combined with other sensor values to be able to make inferences about the wearers' affective state.

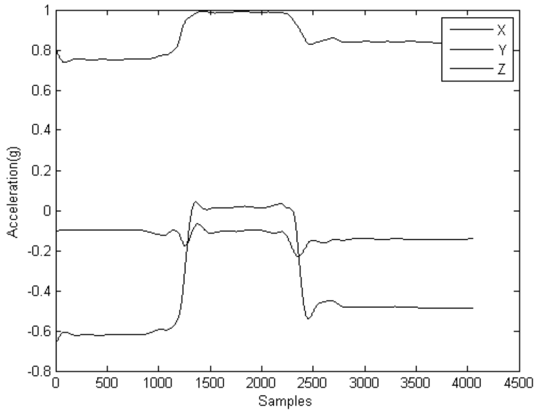

Figure 3: Tri-axial accelerometer signal from a person standing up.

In this signal we can distinguish two parameters: the skin conductance level (SCL) and skin conductance response (SCR). SCL is the slow varying skin conductance, changing over the course of minutes or even hours. SCR is the fast varying skin conductance, changing over the course of seconds. The SCR reflects a person's mental response to fast changing events and are related to various stimuli. In our experiment we focus on the evolution of SCL when maintaining a mental activity during prolonged periods of time.

For performing the measurements we use a device developed by ourselves. Figure 4 shows the device, the electrodes and a simplified diagram of its electronic components. It consists of an ohmmeter and an amplifier with variable gain managed by a microcontroller. It can be connected to a USB port of a personal computer making it possible to analyse the signal evolution in real time. Additionally the device has the capability of working stand-alone with sufficient memory to store data up to 8 hours. We use electrodes made of silver to avoid the chemical attack from sweat.

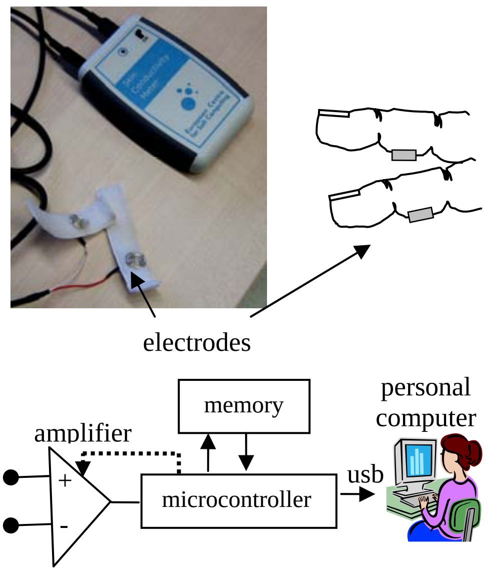

Figure 4: Photography and functional block diagram of the skin conductivity meter.

We have combined the measures obtained from these two sensors to obtain more meaningful information than the one provided by each sensor alone. A similar approach fusing these same sensors has been used in [14] and [6].

3 Linguistic Temporal Model

The concept of Finite State Machine can be extended using fuzzy logic. Moreover, by introducing fuzzy logic in the definition of the different elements of a FSM, we can obtain different kinds of Fuzzy Finite State Machine (FFSM). In the general case a FFSM is a tuple [9]:

FFSM = {Q, X, Y, f, g, s}

where:

- Q is the set of states $\{q_1, q_2, \ldots q_n\}$ where q_i can take values in the interval [0,1]
- X is the set of fuzzy input variables.
- Y is the set of fuzzy output variables.
- f is the state transition fuzzy function
  Q[t] = f (X, Q[t-1])
- g is the output fuzzy function
  Y[t] = g(X, Q[t-1])
- s is the initial state

We use this definition together with the idea by Lotfi Zadeh of converting the signals provided by sensors in perceptions and words [15] [16] to define the concept of Linguistic Temporal Model (LTM) of a process as the tuple {Q, X, Y, R}, where:

- The set Q of states are linguistic labels that represent situations during the system evolution. The model is aimed to represent a process or a set of interrelated processes. Therefore the most adequate linguistic labels are verbs. Note that the data used to determine the state of a process can be the output of a sensor, for example temperature or pressure, but states can also represent more abstract concepts related with the information coming from different sources. In the case of our experiment we identify the state of the LTM with the subject's mental and physical activity.
- X is a set of fuzzy input variables $x_j \in (x_1, x_2, .., x_m)$ with values defined using linguistic labels, such as "the temperature is high". In our experiment x_1 and x_2 are the values obtained from the sensors: Conductivity and Activity.
- Y is a set of fuzzy output variables $(y_1, y_2, .., y_s)$. These output variables can be used to describe aspects of the system at this state that are relevant for our purposes. For example we could be interested in calculating the duration of a state or the power consumption during a state. In our experiment we measure the degree of the subject's stress in every state.
- R is a set of rules that provides the description of how input variables, states and output variables are related and how the system evolves with the time.

The fuzzy linguistic labels associated with Q, X, Y and the set of rules R, are the source to obtain a linguistic description of the modelled process.

To build this linguistic description we have used a paradigm provided by Halliday in his approach to Systemic Functional Linguistics [4]. In SFL the basic element of meaning is the Figure. A Figure contents a Process with Participants and Circumstances. A chain of Figures constitutes a Sequence. In a LTM states and transitions correspond with Figures and the whole LTM correspond with a Sequence. In this way LTM can be used to create a linguistic summarization of the evolution of a process, emphasizing relevant aspects and ignoring the irrelevant ones. In the referenced book 'Construing experience through meaning' is possible to go into details about how to apply SFL with this purpose. In this book Halliday presents his ideas applying them to create recipes for cooking and weather forecast reports.

In the next section we continue our explanation using a practical example of using a LTM.

4 Experimentation

The subjects were wearing the two sensors: The skin conductivity meter fixed attached to the left wrist, with electrodes attached to the index finger and the middle finger. The accelerometer was kept in the chest pocket of the subject's shirt. The subject was instructed to follow the steps of the experiment as described in figure 1.

The states were labelled as:

Q1: Idle

Q2: Working

Q3: Walking

Q4: Relaxing

The inputs are:

Conductivity

Activity

For the sake of simplicity we have normalized all these variables to take values in the interval [0, 1] and for all of them we have used symmetrical trapezoidal linguistic labels Low – Medium – High as shown in figure 5.

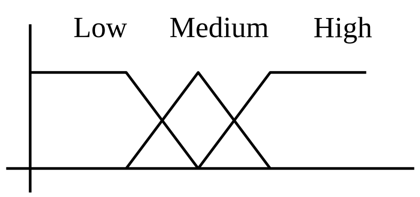

Figure 5: Linguistic labels.

The following is the list of rules R. Note that we distinguish between rules to remain in the state R_{ii} and rules to change to state R_{ij}:

- R_{11}: IF (Q IS q_1) AND (Activity IS Low) AND (Conductivity IS Low) THEN Q IS q1
- R_{12}: IF (Q IS q_1) AND (Activity IS Low) AND (Conductivity IS Medium) THEN Q IS q_2
- R_{22}: IF (Q IS q_2) AND (Activity IS Medium) AND (Conductivity IS Medium) THEN Q IS q_2
- R_{23}: IF (Q IS q_2) AND (Activity IS Medium) AND (Conductivity IS high) THEN Q IS q_3
- R_{33}: IF (Q IS q_3) AND (Activity IS High) THEN Q IS q_3
- R_{34}: IF (Q IS q_3) AND (Activity IS Low) THEN Q IS q_4
- R_{44}: IF (Q IS q_4) AND (Activity IS Medium) AND (Conductivity IS High) THEN Q IS q_4
- R_{41}: IF (Q IS q_4) AND (Activity IS Low) AND (Conductivity IS Medium) THEN Q IS q_1

The subject started {L, M, H} relaxed at the desk at {TIME1}.

The subject was working during {DURATION1} minutes without signs of tiredness.

Around {TIME2} the subject was moving and appears uncomfortable.

At {TIME3} the subject decided to take a walk outside and went back at {TIME 4}

Around {TIME5} the subject was relaxing until to be {more, a lot more} relaxed.

About {TIME6} the subject was available to start to work again.

Figure 6: Example of template for the linguistic report

This set is only a meaningful subset of the total set of needed rules. For the practical implementation it was needed add a complete subset of rules for remain in every state and other to change to the next state.
We like remark that, in the current status of our research, the linguistic labels shape and the rules must be adapted manually to every subject.
We have implemented computationally a motor of inference that makes it possible to calculate, from the values obtained from the sensors, the degree of activation for each q_i and identify the changes of state when the activation of the next state remains high after a short period of time.

In agreement with the Halliday paradigm we have created a template for the linguistic description that is the goal of this work. Every clause refers to a specific process, the subject of the experiment is the only participant and the input – output variables represent the changing circumstances. See in figure 6 an example of template. Obviously there are many possibilities and the structure of the template will vary depending on the application.

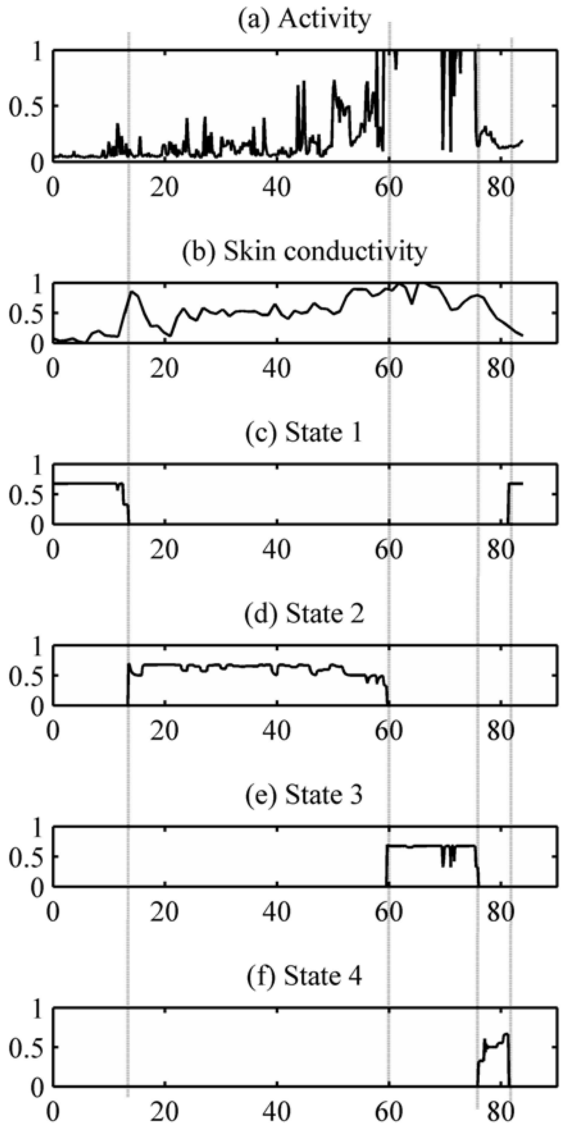

Figure 7 experimental results

Note that "Degree of stress", TIME and DURATION are output variables of the LTM.

The figure 7 shows the result of an experiment where the subject followed successfully the protocol of the experiment during a cycle that took approximately 90 minutes.

Figure 7(a) shows the evolution of the Activity. Note that the body's movement was incrementing during an hour until the subject decided to take a walk of 15 minutes (60-75 minutes). Then the subject went back to the seat.

Figure 7(b) shows the evolution of the Conductivity. Note that we are representing the inverse of the electrical measure in such a way that the signal increases when the degree of arousal grows up. See an initial peak about the 12 minutes that is also detected by the activity sensor. Then the signal continues increasing and is limited during the walk. Finally shows a strong decreasing of the arousal degree (SCL) when the subject is asked to be relaxed.

Figures 7(c), 7(d), 7(e) and 7(f) show the degree of triggering of the "rules to remain" in every state. The results show that the set of rules is able of distinguishing between the four states.

The subject started ***VERY*** *relaxed at the desk at* ***0*** *minutes.*

The subject was working during ***15*** *minutes without signs of tiredness.*

Around ***25*** *minutes the subject was moving and appears uncomfortable.*

At ***60*** *minutes the subject decided to take a walk outside and went back at* ***75*** *minutes*

Around ***80*** *the subject was relaxing until to be* ***ENOUGH*** *relaxed.*

About ***90*** *minutes the subject was available to start to work again.*

Figure 8: Linguistic report

Figure 8 shows the linguistic summarization of the whole process that was obtained using these data.

The linguistic labels VERY and ENOUGH to measure the degree of relax were obtained with a set of rules from the values of Activity and Conductivity. See in figure 8 an example of the obtained linguistic report.

5 Conclusions

This paper presents several tools to research in the fields of Human Activity Monitoring and Affective Computing:

A Human Activity Meter device and a Skin Conductivity Meter device have been described. It has been demonstrated that the combination of their measures can be used to obtain useful information for human activity recognition.

As far as the affective states change gradually, Fuzzy Finite States Machines have been presented as useful tools for modeling the human affective state evolution. The concept of Linguistic Temporal Model has been introduced.

Systemic Functional Linguistic has been introduced as a possibility to create linguistic reports from the data obtained using a LTM computational implementation.

A simple experiment has been presented that describe how to use these tools. The preliminary results obtained are hopeful. The results can be used as a basis for creating proactive systems aimed at helping users to improve the performance of their mental and physical capabilities. Moreover the performed experiment could be used as a starting point to create a system to be used as a complement during an anti-stress psychological therapy.

This work is a small step in a long way. The devices must be reduced in size and made more comfortable to be worn. The theory of LTM must be developed, in special its relation with Systemic Functional Linguistic. The experiments must be extended to a larger number of subjects in order to obtain statistically significant results.

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