Physiological Data in Living Environments

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Abstract: In this paper we develop three ideas for possible scenarios in future living environments. These ideas are based on technology which is present at the moment but may be deficient or not used in living environments. This paper focuses on showing possibilities, while knowing but neglecting actual practical problems. After introducing the potentials of physiological data, we present ideas for different scenarios. The first is concerned with games, trying to neglect the age differences of users and even up the difficulties in game-play. In the second scenario we show a concept for a supportive kitchen utilizing a brain computer interface and gesture detection. In the last scenario we present a draft for smart notification based on mental load. The ideas in this paper are not limited to elders or handicapped people, but most of them can be used to improve their lives.

1 Introduction

In future living environments many different users have to be addressed, when realising a user interface. In addition a new complexity of controlling all the devices in a living environment arises. Such a fusion of devices may lead to synergetic effects, but will also induce higher demands on the user. In the following we explore the potentials of using physiological data in the context of living environments. We explain several physiological measures and show how these can be used for different ways of interaction. This paper is structured as follows: After introducing the technology used and setting some fundamentals, we present different more or less futuristic scenarios based on actual technology. In the first scenario, differences in age and skills while playing computer games get neglected using in-game adaptations based on physiological data. In the second we show an automated kitchen and how table top, gesture detection and brain computer interface (BCI) technology can be combined and integrated. In the third scenario a concept for smart notifications based on the user state will be presented. Finally we draw conclusions implied by this paper.

2 Background

Different physiological signals of a user can be obtained. In our work we focus on cardiovascular activity, electrodermal activity and BCIs. In this section we present related methods and devices.

(a) Chest strap with radio transmitter

(b) ECG with 3 electrodes

(c) Portable EDA device with 2 electrodes

(d) The Emotiv EPOC headset (left rear view)

Figure 1: The different devices used in this work for measuring the physiological data.

2.1 Cardiovascular Activity

The cardiovascular activity of a user can be measured with an electrocardiogram (ECG). Several components of an ECG can be analyzed to determine the user state. The most common used are heart rate and heart rate variability.

2.1.1 Signals and Measurements

Heart Rate The heart rate (HR) is defined as the number of heart beats per minute. The HR can be affected by different factors like age, illness, physical training and breathing [Man08]. It can also be influenced intentionally by the user.

Heart Rate Variability To measure the heart rate variability (HRV), the time between two R-peaks in an ECG is measured. The variability of this measured time intervals is defined as the HRV. The HRV is one of the most used measures for determination of a user's mental load [SFM+01]. Several methods exist to conclude on this status [MBC+96, RSI98, Man08]).

2.1.2 Devices

To measure an ECG several devices exist; for example, stationary ECG devices, with 3 electrodes or more (figure 1b). The shown device needs a wired connection to a computer, for submitting data online. The 3 electrodes have to be attached to the chest of the user according to specific positions, depending on the chosen method of measurement. For the purpose of measuring HRV and HR, heart rate monitors, commonly used in sports, are applicable (figure 1a). An example setup, calculating the low frequency power spectrum, is described in [SK10]. In comparison to stationary devices, heart rate monitors used in sports are very comfortable to wear and allow wireless data transmission.

2.2 Electrodermal Activity

2.2.1 Signals and Measurements

Beside the cardiovascular measurements electrodermal activity (EDA) is one of the most commonly used physiological measures. The signal arises from electrical changes on the skin surface and can be split into tonic and phasic values [Bou88]. Tonic values are represented by the skin conductance level (SCL). The phasic component is called skin conductance response (SCR) and relates to certain stimuli. Every person shows a certain amount of non specific electrodermal reactions (NS.SCRs) per time. EDA is linearly correlated with a persons arousal [Lan95] and stands for emotional reactions and mental activity [Bou88].

2.2.2 Devices

The most common way of measuring EDA is by placing 2 electrodes on the palm. Devices can be stationary or portable (figure 1c). EDA measuring in general is unobtrusive. Recent work towards more comfortable devices led to the design of the Q-Sensor [PSP10]. This device is wearable at the wrist like a watch. Additionally the next generation will support wireless data transfer. This creates new opportunities for long term measurement in a living environment while people can follow their daily activities.

2.3 Electroencephalography

In this work we use electroencephalography (EEG) as base for a BCI. A BCI provides a direct way of communication between a user and a computer. In this case, direct communication means without the detour of using any muscular movement. This direct link is for some people (e.g. locked-in-patients) at this time the only possible way of communication with their environment [Moo03]. There are different approaches for obtaining signals from the brain. At the moment the EEG-based approach is the most promising, not only based on the fact, that it is the only portable one. A BCI can be used as an active and passive interface. This differentiation is based on how signals can be influenced by the user. An active signal needs a direct mental action produced by the user, such as focusing an object or thinking of something special. A passive signal can not be influenced directly, an example is the emotional state.

2.3.1 Signals and Measurements

P300 A P300 is an event related potential (ERP) and describes a wave of positive-going scalp-recorded brain potentials. In detail a P300 is a complex of waves and consists at least of a P3a and a P3b wave [Pol03, Pol07]. The first is best measured with frontal and central positioned electrodes and has its peak in a range of 250 to 280 ms after the stimulus. The second is best measured over parietal brain areas and has a task depending latency of 250 to 500 ms [CMC+09]. In case of this work, the P300 is a response to an infrequent, task-related stimulus, often evoked by using the oddball paradigm [SSH75]. The basic principle of an oddball paradigm is presenting a composition of high-probability non-target elements mixed with low-probability target elements. The latter will invoke the P300 response, which most likely can be detected after some repetitions.

Steady State Visually Evoked Potentials The steady state visually evoked potentials (SSVEPs) are the brain's response to a visual stimulation given at a specific frequency [WZGG04, CGGX02]. The response to this specific frequency is measurable as electric activity in the same or a harmonic frequency [BPS+03].

2.3.2 Devices

At the moment there are a variety of different electroencephalography (EEG) devices used for BCIs. A useful subdivision for this paper is probably a division in portable and not portable devices. All medical EEG devices are for stationary use and not portable while recording data. Medical EEGs also disqualify in terms of usability, because of their complicated set-up procedure, even if they have a better resolution. Non-medical BCIs are primary used for gaming and marketing research. These BCIs lack in accuracy, but can be used more easily. At the moment the Emotiv EPOC BCI (figure 1d) describes some sort of compromise. The Emotiv BCI can be mounted in a short time by a single user and is usable for more complex tasks, though some restrictions apply [PK10].

3 Possible Interactions

Physiological data leads to new ways of interaction. In this chapter we show several possible interactions in the context of living environments.

3.1 Raise/Drop Heart Rate

A possible interaction is raising and dropping of the HR. Raising the HR can for example be achieved by doing physical exercises. The raise of the HR could be used bound to a specific time interval, so that the user has to raise the HR to a certain level, holding it for a given time. Then the user has to calm down and relax, to achieve a dropping of the HR. To ensure that a user does a certain amount of sports, a possible interaction for, example for games or health applications, would be to raise the own HR to a certain level for a given time. On the other hand the interaction to drop the HR could be used for relaxation.

3.2 Adaptation to Mental Load

Based on the HRV the mental load can be used as a passive interaction. The HRV can not be influenced directly by the user. The mental load could be used as a part of the user state to indicate if a user is under mental stress. Depending on the level of mental stress, the user interface can adapt to this state. In contrast to many other possibilities of measuring the mental load, measuring the HRV does not require a direct user interaction.

3.3 Adaptation to Arousal

An increasing number of specific electrodermal reactions per time frame indicates a change in the user's arousal. As succeeding SCRs add up, the overall EDA signal is increasing if a user is exposed to continuous stimuli. While relaxing the signal drops back to a certain baseline.

3.4 Selection

When using an EEG-based BCI a selection mechanism can be implemented at least in two different ways. The first is utilizing the P300 waves and the oddball paradigm, the second is by using SSVEPs. If using the first way the principle is the same used in a P300-Speller [FD88, PK10]. The focused object gets selected by flashing empty spaces or spaces surrounding objects in contrast to flashing the surrounding space of the chosen object, which evokes a P300 response. This works for physical and virtual objects [YDTS10].

The approach based on SSVEPs highlights all objects of the selection at once, but uses different flashing frequencies for each highlight. The flashing frequency of the object focused by the user produces a measurable response in the brain. The given response consists of brain activity in the same or a harmonic frequency as used by the stimulus [BPS^{+}03]. Both approaches can be used to implement a selection.

4 Possible Scenarios

In this chapter we introduce some scenarios based on physiological data. These scenarios are a selection based on our previous and recent work.

4.1 Adaptive Age Neglecting Games

People in living environments are of different age and have different knowledge and preferences regarding entertainment technologies. Therefore playing together or using game based learning, targets different audiences, sometimes even at the same time. Physiological measures can be used to cope with the differences. They provide input for creating more adequate and constantly modulating experiences, specifically tailored to the users needs and interests. The task is to detect and interpret the user state in order to create a supporting or challenging response of the system.

4.1.1 Adaptation to Player Status

The usual way of adapting a game to its player is by calculating the game performance based on game statistic values. According to this approach the game can react to the fact that a player is rather successful in achieving certain goals. However this method does not take into account the player's status. A high performance level can either be a result of constant stress (the player is nearly at his skill limits) or mental underload (the player is not challenged sufficiently). In contrast physiological feedback can adapt the game more specifically and can therefore be way more effective than performance feedback [RSL05]. Additionally the quality in game adaption through physiological feedback is independant of the amount and quality of statistic values available through the game context. Findings of our recent work [Rei11] show that the implementation of a smartphone game based on physiological data results in an individually adapted gameplay. A significant difference in EDA measurement was detected by comparing the adaptive game to a version without integrated physiological feedback. In case of the non adaptive version the plotted EDA value of each player tends to rise. The adaptive version shows a more flatened and in clonclusion adapted EDA curve.

4.1.2 Scenario

In this scenario, two people with different gaming experience and of different age play a multiplayer game on separate devices. One player has no experience with the game device or with gaming at all. The other player is an experienced player, enjoys playing games on different platforms and uses the device on a daily basis. Normally this leads to frustration on the side of the inexperienced player and boredom on the side of the gaming enthusiast. Therefore the game has to adapt to the divergent characteristics of the players. To achieve this, physiological parameters of both players are used as additional input modalities. Based on these measurements a feedback controller in the game can interpret and react to the current user state. The resulting reaction of the system is generated through visual, acoustical or haptic feedback. This feedback influences in turn the physiological reactions of both players. A so called closed feedback loop is generated [PBB95]. The game can support the inexperienced player while exposing the gaming enthusiast to greater challenges. It compensates the differences in learning curves and adapts to constantly changing demands.

4.2 A BCI extended On and Around the Surface-Tabletop Kitchen

At this point, we create a kitchen scenario, which is possible today. In this kitchen we combine elements from more than four different disciplines, which are normally separated. The main elements are borrowed from classical table top, gesture recognition, automated (self organized) storage and transport systems and BCI.

4.2.1 The Main Kitchen Elements and their Advanced Functionality

The Counter Top In this scenario the counter top is a large table top. We assume the counter top as a large display, where information can be shown on every free, uncovered spot. This can be realized through hidden projectors mounted under the kitchen cabins or by integration of displays into the counter top.

The Kitchen Cabinets The cabinets are much alike normal kitchen cabinets, except all cabinets are connected and have continuous shelves. Dividing walls on the inside have been removed. Somewhat special is an elevator system, which connects the shelves of the cabinets to the counter top. This elevator system can be realized as some sort of gripper system or as a traditional elevator system. The first is more complex, but can be useful for other purposes. The refrigerator should be constructed and integrated in the same manner.

The Storage and Transport Units Everything that is stored in the kitchen cabinets is stored in mobile storage units. These storage units consist of two elements. The upper element is a nearly normal kitchen storage container, maybe like the famous Tupperware containers. The bottom element is basically an autonomous transport unit. The main function of this unit is to transport the storage unit on a given path through the system. To avoid getting stuck or collision problems, the whole unit should be as rounded as possible. As an extension, every transport unit is equipped with a kitchen scale to gather weight information. Each transport unit is connected to a central control unit, which organizes and controls the movement of the units and all other actions taking place in the kitchen.

The Central Control Unit All control, organisation and communication tasks concerning the kitchen are handled by the central control unit. This unit delegates as much work as possible to autonomous self-organized units, like the storage and transport units. Some tasks are handled directly by the central unit or are only supported by other units. An example for a central unit task is keeping track of the supplies, based on the kitchen scales data transmitted by the transport units and the best-before date gathered when supplies enter the system.

The User The most important part of the system is the user. This scenario can be seen as a support system for users with constrained movement, but it can also be seen as a system of comfort. However, the user in this scenario has a special feature, the user is wearing a portable (EEG-based) BCI.

4.2.2 User Perspective: Support for a Rather Normal Cooking Task

At first the user chooses a recipe. A selection of possible dishes will be presented by the central system at the nearest free space on the counter top near the user. The selection is based on the availability and weight information provided by the storage and transport units. After completing the selection, the chosen recipe, including a timeline, will be projected next to the hob. When the recipe is chosen the system starts arranging the needed supplies at the counter top. The directly needed supplies are arranged within reach around the hob, while the later needed supplies and possible alternatives are arranged within sight. If there are more than one eligible supplies within sight, a selection can be made based on a combination of on and around the table gesture recognition and a BCI. The selection is divided into two parts. In the first part a group of supplies is identified by a long distance pointing gesture [HLL$^+$12]. In the second step the user picks the required unit using a BCI based selection. Depending on the circumstances a P300-based [YDTS10, PK10, FD88] selection or a SSVEP [WZGG04, CGGX02] approach can be used.

The selected unit will be moved within reach immediately. It is possible to distinct between a selection for usage, transporting it to the cooking area and just gathering some information about the ingredients without moving the transport and storage unit. This can be done by using a pull-gesture (gathering information) or a pick-gesture (selecting as ingredient) after completing the selection [HLL$^+$12]. After usage, the storage units move out of direct reach, but stay within sight. When the cooking is finished the storage and transport units move back to their storage positions in the kitchen cabinets.

4.2.3 Central System Perspective: Hidden Background Tasks

The first task for the central system is to analyse the available supplies and present possible recipes based on this data. After a recipe is selected, the system has to coordinate the movement and the ordering of the transport and storage units from the storage spaces to the counter top. This can be done easily with reserved fairways and parking lots used as shunting routes. Storage systems of this kind can be found nowadays in pharmacies or warehouses. Depending on the realisation, the central system can pass some tasks to the autonomous or self organized transport and storage units. All the ingredients of the recipe, which are not for direct use, taken as possible alternatives or for spicing up, are placed within sight but not within range of the cooking area. The cleaning, especially after the cooking, can be supported by autonomous hoovering and wipe robots.

Special Cases and Side Effects In this scenario we concentrated on transport and storage units for ingredients, but they can also be used for dishes, cutlery, pots and pans. The system works similarly with respect to the weight and size of the object. A positive effect could be an automatic ordering system if some supplies are depleted or expired the best before date. It is also easily possible for the system to make order suggestions based on the actual offerings of the preferred supplier.

4.3 Smart Notification

Notifications can have a different level of importance or can occur in different situations. In some situations it might not be appropriate to notify the user about an unimportant message. In our scenario we describe how the state of the user for a notification system could be determined. Furthermore we will describe what ways of notification could be used in a living environment.

4.3.1 User State

Different possibilities for determination of the user state exist. As described in 3.2 the mental load can be determined by HRV and used for adaptations. Other possibilities to determine mental load are pupil dilatation [IZB04], questionnaires or performance measurements. Physiological measures have the advantage, that they are unobtrusive and do not need interaction by the user. Questionnaires have the disadvantage that they interrupt the user during the task. Performance measurements need interaction on a task [SFM00]. Today many HRV sensor devices are comfortable to wear, like the chest strap used in [SK10]. Most likely they will get even more comfortable in the future. For example it could be possible, that measures like temperature or HR are collected by a patch on the skin or a tiny chip under the skin. To improve the determination of user state, context information, e.g. if the user is moving, is needed. For this context information the sensors of mobile phones or a motion tracking of a person could be used.

4.3.2 Ways of Notification

In living environments notifications are not limited to one device. In our previous work [SSK11] we describe an email notification icon changing its highlighting and visual appearance. In this case the icon is in the system tray of a Windows desktop computer and HRV is measured. A first study was conducted and showed a correlation between time needed to recognize the icon and mental load based on HRV. Another realisation of a notification system based on the interruption level of the user was realized for mobile phones [CV04]. These examples and ideas can be carried on for living environments. In our following scenario, we describe how the notification of an important email or any other message could be done under different levels of mental load in a living environment. In this scenario we distinguish between high and low mental load.

High Mental Load Based on the position of the user in the living environment the way of notification could be chosen. With the help of person tracking or eye tracking, a notification could be displayed at the current position and it could be determined which way the user was looking. For example, instead of showing a notification icon for a very important email on the system tray of the desktop computer, the notification could be shown on the display of the refrigerator in the kitchen, if the user is in the kitchen. In the same way, the notification could be in the form of a voice notification, if the user has a high mental load, and would not recognize the notification in any other way or is not near any device that could display the notification. The intensity of the notification can be adapted to the level of mental load.

Low Mental Load When the mental load of the user is low, a simple notification is appropriate. Similar to the scenario for high mental load, the position of the user can be used to choose the device for displaying the notification. In contrast to the high mental load scenario a visualization with a low intensity should be sufficient.

5 Conclusion

Physiological data has great potential in living environments, even if there are some limitations. We proposed several possible interactions based on physiological data in the context of living environments and introduced different scenarios where they prove to be beneficial. Our previous work concerning physiological data in games [Rei11] and for notification [SSK11] support this statement. In the context of physiologically enhanced gaming it will be possible to compensate the differences of age and experience in gaming. This can open the field of gaming to new groups of users, which could not participate because of their lack of skills. As research in adaptive gaming evolves, physiological data as additional or even as main game control can help to integrate disabled people who are nowadays unable to use standard controls. We proposed a system for notifications which adapts to the user state, e.g. mental load. This addresses the heterogeneous user group in living environments. Reaching the targeted user without distracting the surrounding users stays an open problem. By fusing physiological data and especially BCIs into the living environment the environment gets more sensitive to its user. Additionally, uncomfortable situations can get more comfortable, not only for handicapped persons. A current usability problem is the mounting of the measurement devices. We strongly believe, that the stand alone systems, as they currently exist, will not survive in future. Most of the nowadays separate systems will fuse into ubiquitous support systems. In this matter, important elements concerning the acceptance of such systems will be usability, especially a simple configuration and a trustworthy handling of sensible user data. This will result in better system usability and more capable computer systems which will result in enhanced quality of life.

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