Affective Gaming: A Comprehensive Survey

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Abstract

A typical gaming scenario involves a player interacting with a game by a specialized input device, such as a joystic, a mouse, a keyboard etc. Recent technological advances have enabled the introduction of more elaborated approaches in which the player is able to interact with the game using his/her body pose, facial expressions, actions, even his physiological signals (heart beat rate, encephalogram, skin conductivity etc). The future lies in 'affective gaming', that is games that will be 'intelligent' enough not only to extract the player's commands by his speech and gestures but also by his behavioral cues, and his/her emotional states and adjust their game plot accordingly, in order to ensure more realistic and satisfactory gameplay experience. In this paper, we review the area of affective gaming by describing existing approaches and discussing recent technological advances. We elaborate on different sources of affect information and summarize the existing commercial affective gaming applications. We proceed with outlining some of the most important problems that have to be tackled in order to create more realistic and efficient interactions between players and games and conclude by highlighting the challenges such systems must overcome.

1. Introduction

Affective gaming refers to the new generation of games in which the players' behavior directly affects the game objectives and gameplay. The emotional state and actions of a player can be recognized and used in order to alter the gameplot and offer an increased user experience feeling. In other words, the emotions and actions of a player are of extreme importance, as the behavioral cues extracted from them will define the way the game will progress.

Initial approaches on the field of affective gaming focused on processing the physiological cues of a player in order to correlate them with certain behavioral patterns that would assist in making the player-game interaction more realistic. To achieve that several physiological signals were employed, such as heart beat rate, skin conductivity etc, using obtrusive devices. The use of brain signals also defined a field on its own, leading in the creation of Brain Computer Interface (BCI) systems. The most recent approaches tried to create wearable systems that were built of portable devices/personal computers and thus eliminated the effect of sensors as they provided the player with extra degrees of freedom. However, the main problem with employing specialized sensors to extract behavioral cues is that they greatly affect the immersion of the player in the game. Even with sensors that are relatively easy to use, such as skin conductivity sensors, the player's actions are constrained by the space limitations of each sensor. This is of great importance as it usually leads the player to exhibit unusual behavioral patterns often attributed to the effect (even subconscious one) that the presence of a sensor has. Recent technological advances have opened new avenues towards more realistic human-machine interaction systems, thus enabling the introduction of games in which the player is not only able to control the game but also can control the gameplot and gameplay experience without using an input device, just by freely acting on his/her will. By providing such a real time and robust solution to the tracking problem, the shift has been now shifted towards affective gaming scenarios. In this paper we will review the area of affective gaming. More precisely, we will briefly review the most recent existing approaches and discuss the latest technological advances.

The remainder of the paper is organized as follows. We first present the different sources of affect information, categorizing them in those that involve vision based techniques (Section 2.1), Brain Computer Interface systems (Section 2.2) and those that employ specialized sensors (Section 2.3). We summarize the existing affecting gaming commercial applications in Section 2.3.5. We discuss the challenges that affecting gaming systems must overcome (Section 2.4) and draw our conclusions in Section 3.

2. Sources of Affect Information

2.1. Vision-based

In this Section we will review existing methods that extract affect information using vision-based techniques. This includes unobtrusive methods that do not limit the freedom of the player, allowing him/her to freely act on his/her will. These methods mainly attempt facial expression and body action recognition, as those are behavioral cues that can be easily obtained using, in most cases, low cost cameras.

2.1.1 Facial expressions

Affect recognition systems that exploit facial expression information in reality recognize the visual manifestation of a person's emotion. This is of great importance as facial expressions are better communicated than body actions [13]. The recognition of the actual emotion a person remains a non trivial task, as the person can deliberately try to communicate an emotional signal. The existing systems try to associate the facial appearance with a predefined set of prototypic emotions, whose visual manifestation is universally accepted, regardless of different cultural and geographical variations. Several problems remain to be tackled in order to achieve satisfactory facial expressions recognition, among which scale and resolution issues, illumination changes, pose variations and of course the way each person communicates his/her emotions through facial expressions. A great number of methods that attempt facial expression recognition have been proposed through the years. An interested reader can refer to [48] and the references within for a brief introduction on recent advances of facial expressions and communicated affect. The only approach that directly links facial expressions to games is that presented in [3].

2.1.2 Body actions

Both sources of information play an important role in communicating a player's affective state. However, facial expressions are easier to control than body postures when people want to hide their emotions [14]. Thus the recognition of body actions/postures is of profound importance. The small number of approaches that have been presented towards this direction, mainly focused on extracting information using cameras. More precisely, in [49] the authors extracted visual information of expressive postural features from videos capturing the behaviour of children playing chess with an iCat robot, while in [2] the authors employed computer vision techniques to capture the player's behavior to adapt the game and maximize the player enjoyment.

2.2. Brain Computer Interfaces

Brain signals (Electroencephalography (EEG) and the recently introduced near-infrared spectroscopy (NIRS) and functional NIRS (fNIRS)) have been extensively used in the past as a mean for detecting activity from different brain regions associated with different brain functions (affect, perception, imaging, movement etc.). A review of classification algorithms for EEG-based brain-computer interfaces can be found in [36]. For a brief review of BCI systems for games an interested reader can refer to [41]. In [42] the authors reviewed BCI research from the viewpoint of games and games design. In [55] the authors reviewed several applications of a newly introduced mean of BCI. In [15] the way Physiological Computing (PC) and BCI may be used to enhance computer games was discussed. In [46] the authors reviewed BCI systems for virtual reality control. A research to find out what the differences are between using actual and imagined movement as modalities in a BCI game was conducted in [62]. In [6] the authors discussed the consequences of applying knowledge from Human-Computer Interaction (HCI) to the design of BCI for games.

2.2.1 EEG BCI

Electroencephalography (EEG) measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. To achieve that it employs a number of electrodes placed on the scalp, measuring electrical activity. The vast majority of methods proposed for BCI systems employed EEG signals. In [29] the authors presented an independent non-invasive EEG-based online-BCI as well as setups where the user was provided with intuitive control strategies in plausible gaming applications that use biofeedback. In [8] the authors presented a work that aimed at assessing human emotions using peripheral as well as EEG physiological signals. In [35] the authors experimented with ten naive subjects to train them in a synchronous paradigm within three sessions to navigate freely through a virtual apartment, whereby at every junction the subjects could decide by their own, how they wanted to explore the virtual environment (VE). In [5] some examples of monitoring of mental states and decoding of covert user state and discussed distinct methodological improvements required to bring non-medical applications of BCI technology to a diversity of layperson target groups, e.g., ease of use, minimal training, general usability, short control latencies were presented. In [59] brain imaging was used to passively sense and model the users state as they perform their tasks.

Some of the approaches followed examined the so called steady-state visual evoked potentials (SSVEPs) (signals that are natural responses to visual stimulation at specific frequencies, usually observed in retina changes) or on steady-state somatosensory evoked potentials (SSSEPs) (electrical potential recorded from the nervous system of a human or other animal following presentation of a stimulus). In [39] the authors developed the Bacteria Hunt game, using Steady State Visually Evoked Potential and relative alpha power. In [67] the authors presented an independent BCI interface system based on covert non-spatial visual selective attention of two superimposed illusory surfaces.

Other means of feature extraction used in BCI systems involved eyetracking, head pointing devices and questionnaires provided to the players. In [44] the authors created a simple BCI game which they evaluated with fifteen subjects using the Game Experience Questionnaire (GEQ).

2.2.2 NIRS and fNIRS

Emerging BCI systems use infrared spectroscopy (the spectroscopy that deals with the infrared region of the electromagnetic spectrum, that is light with a longer wavelength and lower frequency than visible light) in order to extract features. Only two approaches reported utilize the use of infrared spectroscopy so far. More precisely, in [22] the authors hypothesized that the overall mental workload required to perform a task using a computer system was composed of a portion attributable to the difficulty of the underlying task plus a portion attributable to the complexity of operating the user interface, while in [18] the authors described the fNIRS device that measures blood oxygenation levels in the brain and discussed its potential within the realm of human-computer interaction. More recently, functional near-infrared spectroscopy (fNIRS) was used as a brain activity measurement in BCI systems. More precisely, in [20] the authors tried to distinguish between different levels of game difficulty using non-invasive brain activity measurement with fNIRS. In [50] the authors applied fNIRS to the human forehead to distinguish different levels of mental workload on the basis of hemodynamic changes occurring in the prefrontal cortex. In [58] the authors empirically examined whether typical human behavior (e.g. head and facial movement) or computer interaction (e.g. key-board and mouse usage) interfere with brain measurement using fNIRS and established which physical behaviors inherent in computer usage interfere with accurate fNIRS sensing of cognitive state information, which can be corrected in data analysis, and which are acceptable. In [18] the authors described the fNIRS device that measures blood oxygenation levels in the brain and discussed its potential within the realm of human-computer interaction (HCI). In [19] a software system was developed that allowed for real time brain signal analysis and machine learning classification of affective and workload states measured with fNIRS.

2.2.3 BCI Games

Several of the attempts followed created BCI games or adapted existing games to their proposed BCI framework to illustrate their findings. A brief review can be found in [32]. In [34] the authors showed that ten naive subjects can be trained in a synchronous paradigm within three sessions to navigate freely through a virtual apartment, whereby at every junction the subjects could decide by their own, how they wanted to explore the virtual environment (VE). In [17] the authors created a BCI to be used as an input device to a highly immersive virtual reality CAVE-like system. In [1] Brainball was presented, a game and a research project on methods of human-machine interaction using brain activity. In [33] the authors developed a game in which a tetraplegic subject mastered control of his wheelchairs simulated movements along a virtual street populated with 15 virtual characters. In [61] the authors employed SSVEP brain signals as a virtual joystick to navigate 3D immersive VE. In [37] the authors made an evaluation of a self-paced BCI application conducted with 21 naive subjects. The developed game was inspired by a sequence in Star Wars. In [43] the authors presented a part of the BrainGain focusing on BCI research for healthy users. In [11] the authors presented a haptic-enabled version of the Second Life Client [31], supporting major haptic devices. In [54] a 3-dimensional game for developing balanced brain wave was implemented. In [12] the authors used a P300 based BCI in a fully immersive VE and proposed two ways of embedding the stimuli in the virtual environment: one that uses 3D objects as targets, and a second that uses a virtual overlay.

2.2.4 Haptics

Another mean widely used in affective gaming scenarios is haptic technology. Haptics are devices that exploit the sense of touch by applying forces, vibrations, or motions to the user in order assist in the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices. The use of haptics has been noticeably increased during the last decade. In [45] the authors introduced a haptic interface for brick games. In [7] the authors discussed a multipurpose system that was suitable for especially blind and deafblind people playing chess or other board games over a network, therefore reducing their disability barrier. In [30] the authors created a multi-touch panel by using multi-touch technology in order to construct a suitable game interface and apply it to a game. In [64] the authors created a system model that helped dental students memorize fundamental knowledge as well as the processes and techniques in dental casting. In [63] the authors measured playability of mobile games by comparing two different types of haptic interfaces, namely hard and soft keypad, for mobile gaming. In [24] the authors enhanced the open source Second Life viewer client in order to facilitate the communications of emotional feedbacks such as human touch, encouraging pat and comforting hug to the participating users through real-world haptic stimulation. In [56] the authors presented a haptic system for hand rehabilitation, that combined robotics and interactive virtual reality to facilitate repetitive performance of task specific exercises for patients recovering from neurological motor deficits. In [60] the authors reviewed the history of input methods used for video games, in particular previous attempts at introducing alternative input methods and how successful they have been. In [57] the author presented a set of recommendations for the more efficient use of haptic technology in computer interaction techniques for visually impaired people and those with physical disabilities. In [38] the authors proposed a situated communication environment designed to foster an immersive experience for the visually and hearing impaired.

2.3. Physiological measurements

Most of the approaches followed in the past involve using specialized sensors, mainly physiological and neurological, aiming at extracting behavioral cues. The devices that have been employed can be distinguished in two categories: those that measure human signals that are captured by sensors that require the player's full collaboration and those that measure human signals that are easier to obtain and result in more player-friendly scenarios.

2.3.1 Sensors

Brain - Scalp: Includes devices that record measurements from the head. Their advantages lie in providing high precision and good time resolution, while being relatively easy to use. They are silent, thus enabling easy auditory processing and quite affordable due to their wide spread worldwide. On the other hand, their use introduces artifacts and noise, since the recordings are deeply affected by the presence of motion. Moreover, they offer low spatial resolution.
Magnetoencephalography (MEG): measures the brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain.
Rheoencephalograph (REG) (or brain blood flow biofeedback): measures the blood flow by employing electrodes attached to certain points on the head. To this end it regards the electrical conductivity of the tissues of structures located between the electrodes.
Hemoencephalography: measures the differences in the light reflected back through the scalp based on the relative amount of oxygenated and unoxygenated blood in the brain.
Heart - Blood: Includes devices that record measurements taken from the heart. Their advantages lie mainly in their easy use, their inexpensive hardware and the salient and established measures they employ. On the other hand, their use is intrusive and greatly affected by physical activity. Moreover, their analysis is quite complex.
Electrocardiography (ECG or EKG): measures the electrical activity of the heart over a period of time, by processing electrical impulses acquired from electrodes attached to the outer surface of the skin (across the thorax or chest).
Photoplethysmograph (PPG): measures the blood flow employing a band to the fingers or to the temple to monitor the temporal artery.

Respiration: Includes devices record measurements taken from the respiratory system. Their main advantage lies in providing quantitive assessments of flows, from which respiratory rate can be derived. On the other hand, their use is intrusive as they require the user's collaboration.
Respiratory rate devices (Vf, Rf or RR): measure the number of breaths over a period of time. Pneumograph (or respiratory strain device): measures the expansion/contraction of the chest and abdomen as well as respiration rate by employing a flexible sensor band around the chest, abdomen or both.
Capnometer (or capnograph): measures the partial pressure of carbon dioxide in expired air at the end of expiration, exhaled through the nostril into a latex tube.
Skin: Includes devices that record measurements taken from sensors attached to the skin in order to extract physiological cues. Their main advantage is that they are very simple and easy to use and interpret. They are less intrusive when compared to other devices that measure physiological cues and their cost is significantly lower. On the other hand they are easily influenced by environmental factors, such as temperature, presence of motion, etc. They are also greatly affected by noise and large variations in baseline and responsivity are observed.
Electrodermograph (EDG): measures the skin electrical activity directly (skin conductance and skin potential) and indirectly (skin resistance) by employing electrodes placed over at hand and wrist.
Galvanic skin response (GSR)): (also known as electrodermal response (EDR), psychogalvanic reflex (PGR), skin conductance response (SCR) or skin conductance level (SCL)), measures the electrical conductance of the skin, primarily depending on its moisture level.
Thermometers: measure the body temperature.
Muscles: Includes devices that record measurements from sensors attached to the muscles. Their main advantage

is that their signals are easy to analyse and interpret. Moreover, they are sensitive enough for more challenging cases, such as facial expressions. On the other hand they are expensive and intrusive, as they interfere with muscle groups. Thus it is rather difficult to acquire natural measurements.

Foot Switches: measure the pressure under foot. They are sensitive enough to discern tactile activity and indicate heel strike and toe-off events. The recording device is in the form of electrodes attached to the feet.

Goniometers: measure finger, leg and arm joint angles. The recording device is in the form of electrodes attached to the equivalent body part.

Electromyograph (EMG): measures muscle contraction created due to underlying skeletal muscles activity by employing surface electrodes.

Facial Electromyography (fEMG): measures the facial muscle activity (primarily of the corrugator supercilli and zygomaticus muscles) by processing the electrical impulses generated when muscles contract.

2.3.2 Motion capture systems

Motion capture systems have been also widely used to extract the human body joints information. Most often they consist of markers strategically placed on the joints of a person. These markers operate by reflecting the light emitted by a light source thus making their tracking a very easy procedure. In [65] the author investigated the impact of adaptivity on the physiological state and the expressed emotional preferences of users. In [51] the authors tried to recognize the affective states of players from non-acted, non-repeated body movements in the context of a video game scenario. In [28], [53] the authors attempted recognition of affective states and affective dimensions from non-acted body postures instead of acted postures. Recent developed systems operate without attaching markers on the subject's body but by employing optical motion tracking. Motion capture systems offer a real time solution to the problem of point tracking by extracting accurate information that is relatively easy to process. However, they are obtrusive methods of extracting affect information, as they require (in most cases) the user to be limited by the use of markers.

2.3.3 Wearable games

Wearable games employ specialized devices incorporating computer and advanced electronic technologies. During the last decade, wearable devices have greatly attracted the interest of game researchers/developers. In [21] the authors conducted an initial experiment with inexpensive body-worn gyroscopes and acceleration sensors for the Chum Kiu motion sequence in Wing Chun. In [9] the authors described the efforts on designing games for wearable computing technology taken by the 23 students of the project Physical Environment Games. In [4] the authors used a Global Positioning System (GPS) device to extract the coordinates of the players position and create a game that explorer the ability of one player competing with the others.

2.3.4 Psychophysiological measurements

A brief review of the mainly used psychophysiological measurements can be found in [25]. An interested reader can refer to [16] regarding the use of psychophysiology to communicate the psychological state of the user to an adaptive system. In [66] the authors employed blood volume pulse (BVP) and skin conductance (SC) signals, as well as kids' expressed preferences of how much fun particular game variants were in order to create models of affective state of entertainment ('fun') based on the kids physiological state during physical game play. In [47] the authors studied the neural processing of emotion-denoting words based on a circumplex model of affect, thus allowing the description of all emotions as a linear combination of two neurophysiological dimensions, valence and arousal. In [40] the authors explored game designs to find which work best with different input technologies, either using direct or indirect methods. More precisely, they discussed gaze interaction with an eye tracker, electromyography, GSR, electrocardiography, strain sensors, temperature sensors and electroencephalography and developed an affective input game that employed a console to acquire the above mentioned physiological measures. More recently, the authors in [27, 26] investigated the contribution of body configuration (form) in the automatic recognition of non-acted affective dynamic expressions in a video game context. Another approach by the same authors [52] attempted the recognition of the affective states of players from non-acted, non-repeated body movements in the context of a video game scenario.

2.3.5 Existing commercial games

The commercial affective games that have been developed are the following:

Bionic Breakthrough (1983), a bounce the ball into a brick wall game. The player wears a headband on his head whose sensors are supposed to pick up any facial movements or muscle twitches, in order to control the movements of the paddle and use is as input instead of an ordinary joystick.

Missile Command (1980), in which the player has to destroy moving targets. The heart beat rate of a player is measured and used to change the nature of the game challenge to keep engagement within an optimum range.

Oshiete Your Heart (1997), a Japanese dating game. The heart beat rate and sweat level of a player is measured to

influence the outcome of a date.
Brainball (2003)[23], in which the player's relaxation status, measured using EEG, moves a physical ball across a table between two opponents. The player who is more relaxed wins.
Left 4 Dead 2 (2008) [10], a first person shooter video game. The player's stress level, measured as the electric response of the player's skin, determines the pace the game

2.4. Affective gaming challenges

Several issues have to be tackled in affective gaming scenarios in order to achieve a realistic interaction of the player with the game. First, real-time detection of a player and of his/her body parts has to be achieved. The problem of recognizing his/her actions and emotions has been widely studied in the past, but involving a set of predefined classes. Therefore, the introduction of spontaneity, as the player may express himself/herself in any way that he/she wishes, constitutes an extra challenge. Regarding groups of players, several extra challenges exist, like several occlusions due to space limitations but also to the presence of many people in the same space. The free interaction among the players and the way that affects their subsequent emotions and states is also a novel field of research. After having efficiently recognized the emotional state of each individual player within an action context as performed in the single-player game scenario, the next step is to study the players as members of a social group, that is to identify the way each player interacts with each other and also to identify relationships built within this interaction framework. For example, do a player's actions reveal a friendly/aggressive mood towards the other players? Can we use the player's actions to predict subsequent actions? When it comes to the whole group, do players choose a leader, even subconsciously, whom they tend to mimic? Are cohesion (i.e. tendency of people to form groups) relationships formed? How are all of the aforementioned interactions and relationships developed in time? Can we exploit the information their dynamics have to offer?

Summarizing, affective gaming scenarios involve many interdisciplinary fields. Besides the obvious computer vision techniques that have to be employed to extract behavioral cues, input from psychologists has to be provided in order to properly define the scenario under examination in terms of emotions and personality traits. Which is the role that the expressed emotions play in the overall gameplay experience? How realistic should the expressed emotions be in order to maintain player engagement? What are the possible interactions and the relationships among the players? Which modalities (speech, gestures, facial expressions) should be used and to which should the game emphasize? How should the gameplay be adopted to the players affective states? The challenging nature of the proposed scenarios regarding behavior understanding, in combination with the lack of available datasets, constitutes the proposed research a novel field, even for psychologists.

3. Conclusions

The existing games scenarios seem to have undergone a major transformation through the past five years, due to the recent technological advances that allow for robust, sensorless and real-time interaction of the players with the game. The interest of the scientific community has thus been shifted towards affective gaming during the last few years, as the incorporation of affect recognition in games scenarios allowed for a more realistic gameplay experience for the players. In this paper we elaborated on the existing approaches regarding affective gaming and discussed the recent technological advances that progressed the field. We reviewed the different sources of acquiring affect information and presented the existing commercial affective gaming applications. Last, we discussed about the challenges that affective gaming scenarios have to tackle in order to achieve a more realistic gameplay experience.

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References

[1] B. Z. Allison, B. Graimann, and A. Grser. Why use a bci if you are healthy? In *Advances in Computer Entertainment*, 2007.

[2] S. Asteriadis, N. Shaker, K. Karpouzis, and G. N. Yannakakis. Towards players affective and behavioral visual cues as drives to game adaptation. LREC Workshop on Multimodal Corpora for Machine Learning, 2012.

[3] I. Bacivarov and P. M. Corcoran. Facial expression modeling using component aam models - gaming applications. In *Games Innovations Conference*, 2009.

[4] C. Bertelsmeyer, E. Koch, and A. H. Schirm. A new approach on wearable game design and its evaluation. In *Proceedings of 5th ACM SIGCOMM workshop on Network and system support for games*, 2006.

[5] B. Blankertz, M. Tangermann, C. Vidaurre, S. Fazli, C. Sannelli, S. Haufe, C. Maeder, L. Ramsey, I. Sturm, G. Curio, and K.-R. Mller. The berlin braincomputer interface: nonmedical uses of bci technology. *Frontiers in Neuroscience*, 2010.

[6] D. P.-O. Bos, B. Reuderink, B. van de Laar, H. Grkk, C. Mhl, M. Poel, D. Heylen, and A. Nijholt. Human-computer interaction for bci games: Usability and user experience. In

International Conference on CYBERWORLDS 2010 Human-Computer Interaction for BCI Games, 2010.

[7] N. Caporusso, L. Mkrtchyan, and L. Badia. A multimodal interface device for online board games designed for sight-impaired people. *IEEE Transactions on Information Technology in Biomedicine*, 2010.

[8] G. Chanel, K. Ansari-Asl, and T. Pun. Valence-arousal evaluation using physiological signals in an emotion recall paradigm. In *IEEE International Conference on Systems, Man and Cybernetics*, 2007.

[9] B. Cinaz, E. Dselder, H. Iben, E. Koch, and H. Kenn. Wearable games - an approach for defining design principles. In *Student Colloquium at the International Symposium on Wearable Computers ISWC06*, 2006.

[10] V. Corporation. Left 4 dead 2. `http://en.wikipedia.org/wiki/Left_4_Dead`, 2008.

[11] M. de Pascale, S. Mulatto, and D. Prattichizzo. Bringing haptics to second life. In *Proceedings of the 2008 Ambi-Sys workshop on Haptic user interfaces in ambient media systems*, 2008.

[12] M. Donnerer and A. Steed. Using a p300 brain-computer interface in an immersive virtual environment. In *PRESENCE-TELEOP VIRT*, 2010.

[13] P. Ekman and W. Friesen. Nonverbal leakage and clues to deception. *Psychiatry*, (1):88–105, 1969.

[14] P. Ekman and W. Friesen. Detecting deception from the body or face. *Personality Social Psychology*, (3):288–298, 1974.

[15] S. Fairclough. BCI and physiological computing for computer games: Differences, similarities and intuitive control. In *Proceedings of CHI*, 2008.

[16] S. H. Fairclough. Fundamentals of physiological computing. *Interacting with Computers*, 21:133 – 145, 2009.

[17] D. Friedman, R. Leeb, C. Guger, A. Steed, G. Pfurtscheller, and M. Slater. Navigating virtual reality by thought: What is it like? *Presence*, 2007.

[18] A. Girouard, E. Solovey, L. Hirshfield, E. Peck, K. Chauncey, A. Sassaroli, S. Fantini, and R. Jacob. From brain signals to adaptive interfaces: Using fNIRS in HCI. *Brain-Computer Interfaces: Applying our Minds to Human-Computer Interaction*, 2010.

[19] A. Girouard, E. Solovey, and R. Jacob. Designing a passive brain computer interface using real time classification of functional near-infrared spectroscopy. *International Journal of Autonomous and Adaptive Communications Systems*, 2013.

[20] A. Girouard, E. T. Solovey, L. M. Hirshfield, K. Chauncey, A. Sassaroli, S. Fantini, and R. J. K. Jacob. Distinguishing difficulty levels with non-invasive brain activity measurements, 2008.

[21] E. A. Heinz, K. S. Kunze, M. Gruber, D. Bannach, and P. Lukowicz. Using wearable sensors for real-time recognition tasks in games of martial arts - an initial experiment. In *IEEE Symposium on Computational Intelligence and Games*, 2006.

[22] L. M. Hirshfield, E. T. Solovey, A. Girouard, J. Kebinger, R. J. Jacob, A. Sassaroli, and S. Fantini. Brain measurement for usability testing and adaptive interfaces: an example of uncovering syntactic workload with functional near infrared spectroscopy. In *Proceedings of the 27th international conference on Human factors in computing systems*, 2009.

[23] S. I. Hjelm. Research and design: the making of Brainball. *Interactions*, 2003.

[24] S. K. A. Hossain, A. S. M. M. Rahman, and A. E. Saddik. Haptic based emotional communication system in second life. In *IEEE International Symposium on Haptic Audio-Visual Environments and Games (HAVE)*, 2010.

[25] J. M. Kivikangas, I. Ekman, G. Chanel, S. Jarvela, B. Cowley, M. Salminen, P. Henttonen, and N. Ravaja. Review on psychophysiological methods in game research. In *Proceedings of Nordic DiGRA*, 2010.

[26] A. Kleinsmith and N. Bianchi-Berthouze. Automatic recognition of non-acted affective postures. *IEEE Transactions on Systems, Man and Cybernetics, Part B*, 2011.

[27] A. Kleinsmith and N. Bianchi-Berthouze. *Form as a Cue in the Automatic Recognition of Non-Acted Affective Body Expressions*. Springer LNCS 6974, 2011.

[28] A. Kleinsmith, N. Bianchi-Berthouze, and A. Steed. Automatic recognition of non-acted affective postures. *IEEE Transactions on Systems, Man and Cybernetics Part B: Cybernetics*, (4):1027–1038, 2011.

[29] R. Krepki, B. Blankertz, G. Curio, and K. Mller. The berlin brain-computer interface (bbci) towards a new communication channel for online control in gaming applications. *Multimed Tools Applications*, 2007.

[30] Y.-C. Kwon and W.-H. Lee. A study on multi-touch interface for game. In *3rd International Conference on Human-Centric Computing (HumanCom)*, 2010.

[31] L. Lab. Second life. `http://www.secondlife.com`, 2003.

[32] A. Lecuyer, F. Lotte, R. B. Reilly, R. Leeb, M. Hirose, and M. Slater. Brain-computer interfaces, virtual reality, and videogames. *IEEE Computer*, 2008.

[33] R. Leeb, D. Friedman, G. R.Muller-Putz, R. Scherer, M. Slater, and G. Pfurtscheller. Self-paced (asynchronous) bci control of awheelchair in virtual environments: A case study with a tetraplegic. *Hindawi Publishing Corporation Computational Intelligence and Neuroscience*, 2007.

[34] R. Leeb, F. Lee, C. Keinrath, R. Scherer, H. Bischof, and G. Pfurtscheller. Brain-computer communication: motivation, aim, and impact of exploring a virtual apartment. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2007.

[35] R. Leeb, F. Lee, C. Keinrath, R. Scherer, H. Bischof, and G. Pfurtscheller. Braincomputer communication: Motivation, aim, and impact of exploring a virtual apartment. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2007.

[36] F. Lotte, M. Congedo, A. Lecuyer, F. Lamarche, and B. Arnaldi. A review of classification algorithms for eeg-based braincomputer interfaces. *Journal of Neural Engineering*, 2007.

[37] F. Lotte, Y. Renard, and A. Lcuyer. Self-paced brain-computer interaction with virtual worlds: A quantitative and

qualitative study out of the lab'. In *International Brain-Computer Interface Workshop and Training Course*, 2008.

[38] K. Moustakas, D. Tzovaras, L. Dybkjaer, N. Bernsen, and O. Aran. Using modality replacement to facilitate communication between visually and hearing-impaired people. *IEEE Transactions on Multimedia*, 2011.

[39] C. Muhl, H. Gurkok, D. P.-O. Bos, M. E. Thurlings, L. Scherffig, M. Duvinage, A. A. Elbakyan, S. Kang, M. Poel, and D. Heylen. Bacteria hunt: A multimodal, multiparadigm bci game. In *Workshop report for the ENTERFACE*, 2009.

[40] L. E. Nacke and R. L. Mandryk. Designing affective games with physiological input. In *Workshop on Multiuser and Social Biosignal Adaptive Games and Playful Applications in Fun and Games Conference (BioS-Play)*, 2010.

[41] A. Nijholt. Bci for games: A state of the art' survey. *Ifip International Federation For Information Processing*, 2009.

[42] A. Nijholt, D. P.-O. Bos, and B. Reuderink. Turning shortcomings into challenges: Braincomputer interfaces for games. *Entertainment Computing*, 2009.

[43] A. Nijholt, J. B. F. van Erp, and D. K. J. Heylen. BrainGain: BCI for HCI and games. In *Symposium Brain Computer Interfaces and Human Computer Interaction: A Convergence of Ideas at the AISB 2008 Convention 'Communication, Interaction and Social Intelligence'*, 2008.

[44] D. Oude Bos and B. Reuderink. Brainbasher: a bci game. In *Extended Abstracts of the International Conference on Fun and Games*, 2008.

[45] W. Park, L. Kim, H. Cho, and S. Park. Design of haptic interface for brickout game. In *IEEE International Workshop on Haptic Audio visual Environments and Games*, 2009.

[46] G. Pfurtscheller, R. Leeb, J. Faller, and C. Neuper. *Brain-Computer Interface Systems Used for Virtual Reality Control*. 2011.

[47] J. Posner, J. A. Russell, A. Gerber, D. Gorman, T. Colibazzi, S. Yu, Z. Wang, A. Kangarlu, H. Zhu, and B. S. Peterson. The neurophysiological bases of emotion: An fMRI study of the affective circumplex using emotion-denoting words. *Human Brain Mapping*, 30, 2009.

[48] A. A. Salah, N. Sebe, and T. Gevers. Communication and automatic interpretation of affect from facial expressions, 2010.

[49] J. Sanghvi, G. Castellano, I. Leite, A. Pereira, P. W. McOwan, and A. Paiva. Automatic analysis of affective postures and body motion to detect engagement with a game companion. In *HRI'11*, pages 305–312, 2011.

[50] A. Sassaroli, F. Zheng, L. M. Hirshfield, A. Girouard, E. Solovey, R. Jacob, and S. Fantini. Discrimination of mental workload levels in human subjects with functional near-infrared spectroscopy. *Journal of Innovative Optical Health Sciences*, 2008.

[51] N. Savva and N. Bianchi-Berthouze. Automatic recognition of affective body movement in a video game scenario. In *International Conference on Intelligent Technologies for interactive entertainment*, 2012.

[52] N. Savva and N. Bianchi-Berthouze. Automatic recognition of affective body movement in a video game scenario. In *International Conference on Intelligent Technologies for interactive entertainment (INTETAIN)*, 2012.

[53] N. Savva, A. Scarinzi, and N. Bianchi-Berthouze. Continuous recognition of players affective body expression as dynamic quality of aesthetic experience. *IEEE Transactions on Computational Intelligence and AI in games*, (3):199–212, 2012.

[54] B.-S. Shim, S.-W. Lee, and J.-H. Shin. Implementation of a 3-dimensional game for developing balanced brainwave. In *Fifth International Conference on Software Engineering Research, Management and Applications*, 2009.

[55] R. Sitaram, A. Caria, R. Veit, T. Gaber, G. Rota, A. Kuebler, and N. Birbaumer. Review article fmri brain-computer interface: A tool for neuroscientific research and treatment. *Hindawi Publishing Corporation Computational Intelligence and Neuroscience*, 2007.

[56] M. Sivak, O. Unluhisarcikli, B. Weinberg, A. Melman-Harari, P. Bonate, and C. Mavroidis. Haptic system for hand rehabilitation integrating an interactive game with an advanced robotic device. In *IEEE Haptics Symposium*, 2010.

[57] C. Sjstrm. Using haptics in computer interfaces for blind people. In *CHI '01 extended abstracts on Human factors in computing systems*, 2001.

[58] E. T. Solovey, A. Girouard, K. Chauncey, L. M. Hirshfield, A. Sassaroli, F. Zheng, S. Fantini, and R. J. Jacob. Using fnirs brain sensing in realistic hci settings: experiments and guidelines. In *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, 2009.

[59] D. S. Tan. *Brain-Computer Interfaces: Applying our Minds to Human-Computer Interaction*. HumanComputer Interaction Series, Springer, 2010.

[60] A. Thorpe, M. Ma, and A. Oikonomou. History and alternative game input methods. In *International Conference on Computer Games*, 2011.

[61] H. Touyama, M. Aotsuka, and M. Hirose. A pilot study on virtual camera control via steady-state vep in immersing virtual environment. In *3rd IASTED Conference on Human Computer Interaction*, 2008.

[62] B. L. v.d. Actual and imagined movement in bci gaming, March 2009.

[63] C. Y. Wong, K. Chu, C. W. Khong, and T. Y. Lim. Evaluating playability on haptic user interface for mobile gaming. In *International Symposium in Information Technology (ITSim)*, 2010.

[64] C.-Y. Yang, Y.-S. Lo, and C.-T. Liu. Developing an interactive dental casting educational game. In *3rd IEEE International Conference on Computer Science and Information Technology (ICCSIT)*, 2010.

[65] G. N. Yannakakis. Game adaptivity impact on affective physical interaction. In *International Conference on Affective Computing and Intelligent Interaction*, 2009.

[66] G. N. Yannakakis and J. Hallamb. Entertainment modeling through physiology in physical play. *International Journal on Human-Computer Studies*, 66, 2008.

[67] D. Zhang, A. Maye, X. Gao, B. Hong, A. Engel, and S. Gao. An independent brain-computer interface using covert non-spatial visual selective attention. *Neural Engineering*, 2010.