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INDIRECT BIOFED ARCHITECTURE

Strategies to best utilise biofeedback tools and interaction metaphors within digital architectural environments

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Abstract. This paper explains potential benefits of indirect biofeedback used within interactive virtual environments, and reflects on an earlier study that allowed for the dynamic modification of a virtual environment's graphic shaders, music and artificial intelligence (of Non Playing Characters) based on the biofeedback of the player. It then examines both the potential and the issues in applying biofeedback (already effective for games) to digital architectural environments, and suggests potential uses such as personalization, object creation, atmospheric augmentation, filtering, and tracking.

Keywords. Virtual worlds; biofeedback; sensors; empathy theory.

1. Introduction

This paper argues the converse to the 'liquid architecture' theory of digital worlds posted a decade ago by Novak (1991). Rather than a liquid realm, we may wish for vague digital media boundaries that congeal or even solidify on interaction, in order to direct people into different cognitive realms, and afford a wider and richer range of interactive modes and contextual information. Unfortunately, architecture (as a built place) has too often been viewed as an art form that relies on its aesthetic value in terms of being an immovable and immutable object. For example, in the nineteenth and twentieth century, empathy theorists viewed architecture as little more than sculptural objects that we can create associations for (Mallgrave and Ikonomou, 1994; Leech, 1979; Newmann, 1995). The philosopher Anthony Savile (1993) attacked Richard Foster's work for the same reason as the empathy theorists: treating the essence of architecture as sculptural form. For Savile, architecture also involves interior spaces, the linking of spaces (e.g., from inner to outer and the converse), and the placing or locating, using and imagining of symbolic objects (as well as the self and other people) in order to create a significant sense of place.

However, virtual worlds and digital architecture in general do seem to be abstracted form. The experiencing of architecture in a virtual environment typically lacks the richly embodied and visceral experience of visiting and moving through real world architecture situated on changing terrain and visited during changes of light, heat, atmosphere, and sound. Technical limitations may be part of the issue, but a further factor is the inability of current virtual environments to adapt meaningfully to the participants. Could biofeedback help address this lack of rich embodiment in digital environments?

2. Definition of biofeedback

We use the term biofeedback to represent a real-time two-way feedback loop between the machine and the user: the user reacts to an action initiated by the system, and the system can then react based on the users physical/emotional reaction (and so forth). Biofeedback interaction does not necessarily form the primary mode of interaction, but augments existing interaction. In the following case study we focus on the use of such devices within gaming environments. While the initial implications are for games (Koutepova et al, 2010) there is also widespread potential for many forms of digital interaction (Fairclough, 2009).

5. Biofeedback in computer games

For First Person Shooter (FPS) computer games, biofeedback can help in the visual and audio adjustments of the avatar and HUD (Heads Up Display). Manipulation of the game environment and events, and enhancement of generalised gameplay can be affected (player speed, strength and avatar abilities). Low galvanic skin response helps with aiming of weapons. High heart rate might assist with agility and movement.

There are also stealth games, which could require the user to remain calm while walking through the city, avoiding suspicion, and monitor their breathing and heart rate when using a weapon to perform, say, an assassination.

They may have to raise their heart rate to move faster during an escape, but also keep their skin response low in order to remain focussed. Similarly, for jail breaking: when speaking with Non Playing Characters, or when hiding objects, the user must remain calm to be inconspicuous. Traditional game interfaces to accomplish these kinds of interaction do not create a breakdown between the user and their avatar.

In the developing world of social player games, biofeedback can also help provide other players with information on the trustworthiness of the player. After all, the lie detector is a simple form of biofeedback. Biofeedback can also be used to trigger automatic facial behaviours or physical gestures in the avatar. Boredom could trigger certain avatar characteristics so that other players realise this player is not fully engaged, but this could also be accomplished with eye tracking, which is part of the CALLAS research project (2010), but not discussed in this paper due to space restrictions.

4. Past work: case study

In the following case study (Dekker and Champion, 2007) we investigated how commercial biofeedback devices could be integrated with existing computer game environment. This study utilised the Wild Divine sensor technology, which includes a device that clips onto the fingers. The Lightstone measures the ECG HRV (Electrocardiogram Heartrate Variability) and the GSR (Galvanic Skin Response) of the user in real-time. While these measurements do not give enough information to make a complete Biometric Analysis (Beckhaus and Kruijff, 2003), they provide insight into participants' reactions to specific game events.

Figure 1: Wild Divine Lightstone biofeedback sensor

The Lightstone device (Figure 1) has the potential to measure: anxiety and stress, relaxation and meditation, tension, sudden changes in mood, and breathing variability. EEG was not used due to ethical considerations.

We developed sockets for the Wild Divine biosensor, enabling us to use them for commercial games and for virtual environments. We conducted tests on fourteen users, and found some interesting results. For our experimental design we modified an existing zombie horror level developed in the Half-life 2 Source game engine by connecting wild divine sensors. Invisible boxes in the game level detected the biofeedback, and depending on the biofeedback registered whether the user was calm or excited, creating changes in apparent time (bullet time effects), music, and visibility (a calmer participant could see through walls or even become invisible to their enemies.

Filters (Figure 2) were also applied to the game if the player's heartbeat was faster or slower than average. If the user's heartbeat and galvanic skin response was over 3 times their average, the screen became bright red, the field of view of the avatar would change to 130 degrees and the speed of the avatar would dramatically increase (to simulate a 'berserker'). A calmer heartbeat turned the display black and white or faded it to white, while an excited heartbeat caused the display to fade to red or further, to shake, to represent a lack of control.

Figure 2. Half Life 2 and Biofed Shaders

To compensate for possible problems associated with this method of analysis, readings were averaged at two-second intervals. The current average of the participants' biometrics were compared against the calibration average, to create a multiplier. The three multipliers (heart rate variability, skin response and heartbeat) dynamically changed the game environment.

Some observations: participants' changes in facial expressions were easily comparable to the change in biometric information (we also used video cameras to track the players and the onscreen action). Audio effects had a considerable effect on participants' biometric information and reactions. The dynamic shaders clearly affected the users. Black and white visualisation calmed users. The red filter visualisation did not affect biometric information significantly. The white screen visualisation confused users. Users seemed more engaged in the enhanced biofeedback version (over the control environment) especially when sounds were played. Users also reacted strongly when the screen shook. Participants realised there was biofeedback but did not try to adjust their breathing or heart rate to see how it affected game-play. In short, indirect biofeedback seemed effective and more engaging than the control (a game level with no biofeedback).

However we are reluctant to recommend further use of the Wild Divine technology. The sensors interfered with hand control, required continual recalibration and occasionally gave unreliable data. While for our research these limitations were acceptable (although some might disagree, such as Kuikkaniemi et al 2010), more recent developments such as Neurosky (Rebolledo-Mendez et al, 2009) and Emotiv (Zintel, 2008) offer more promise in terms of stability and ease of use. The Half-Life 2/ Source game engine also has implementation issues.

Biofeedback and architecture-potential uses

There are various papers and projects on using biofeedback or phobic triggers in virtual environments to either expose and cure phobias, or to develop understanding of oneself, or of others, but we have not encountered discussion on how biofeedback can be used to enhance (digital) architectural appreciation and understanding.

One potential use is for personalization. Digital environments have been criticized for being sterile, and empty, lacking personality, individuality or warmth (Green, 1996; Minocha and Reeves, 2010). Biofeedback could augment and provide individual personalization, adding in unique lighting affects, sounds, or other details relating directly and dynamically to the participant's physiological states.

Biofeedback could also personalize social virtual environments, where multiple people (such as stakeholders in urban design projects) are simultaneously immersed in a virtual environment. They could view or hear how others are reacting to the virtual space. Or perhaps where the virtual world is based on a real-world place, biofeedback from real world passers by and inhabitants could be fed in real-time into the virtual world.

If walking through a virtual environment triggers participants' memories or emotional attachments of the real-world place being simulated, it may be possible to colour or otherwise tag these locations in the virtual environment in relation to the biofeedback being generated. However, this does not seem accurate or reliable. Bored mental states that arise independently of the virtual environment may affect results. Non-visual (not tactile or olfactory or audio) sensations aren't likely to be available via digital media. There may be useful applications in the evaluation of engagement via virtual environments being automatically tagged by the biofeedback of visitors (chairs, rooms or graspable objects could retain a metaphorical aura, for example), but this would be hard to evaluate in small experiments.

There is also the notion of architectural empathy. In a book entitled *Empathy and Its Development* (Eisenberg and Stronyer, 1987), a clear distinction is made between empathy and sympathy (concern for people). Despite various definitions of empathy there is a tendency for empathy to be divided into empirical empathy (by association) or empathy through feeling (also called personal empathy). Empirical or aesthetic empathy involves attributing personal qualities to people *and* to objects, such as columns etc. So one may be able to create differing architectural spaces and evaluate with biofeedback whether they elicit certain responses, but this at least initially appears a highly involved and complex situation to evaluate.

Atmospheric augmentation was carried out in the Ravensholm Wild Divine-Half Life 2 study, uniquely personalized and augmented environments could be created from varying rates of biofeedback. However, how the environment is modified might not necessarily augment the experience during play, and may not even be recognizable (let alone be considered evocative) by the participants. Another problem is that this may *gamify* and *adrenalize* the architectural experience. In other words, enjoyment comes from visceral augmentation, and a rewards system which does not necessarily relate to the architecture as designed, nor help any meaningful experience of the surroundings themselves apart from as backdrop or as *ludic affordances*.

Figure 3. Qumulus interactive real-time weather system using Quest 3D

Perhaps more effectively, biofeedback may be used to augment the overall atmosphere, or even climate. Recent technology has seen the development of real-time interactive weather simulation, and they could also be controlled by biofeedback (Figure 3). However although this external environmental data may add to user engagement, this information is not necessarily relevant to the individuals' goals and emotional state. A more architecturally appropriate interaction metaphor might be linking visual signs of pollution and decay to the overly excited biofeedback, the more excited the player the more quickly the building decays.

Extrapolating from game mechanics, we could leverage biofeedback states that are generated from excitement (or boredom) in games to colour or otherwise alter digital spaces as a reward and feedback system. Architecture can be seen as a complex symbolic relationship of path and centre, of detail at places of rest (such as in formal seating areas), and subdued detail where circulation is important (such as corridors and staircases). If the participant understood a space was designed more for rest than for activity and acted accordingly (such as slowed down their heartbeat and GSR to appropriate levels) the environment could change to reflect their physiological harmony with their surrounds.

Such a scenario might not work so well in a game environment where it would not be clear how activity based biofeedback would give either the participant or the viewer a better idea of how the participant is affected by the architectural quality of the space itself and not just by responses to located events. However it may be appropriate for sacred or mythical spaces, where the calmer the participant is, the richer the interaction afforded, increased environmental details, avatars develop supernatural or mystic powers, or religious beliefs take virtual form.

It is also possible to use biofeedback as an evaluation mechanism, such as evaluating spatial awareness, and detecting potential differences between spatial designers and the public. This technology might be able to detect developing spatial awareness in student designers, and where and when spatial awareness impinges on general awareness in virtual environments.

Biofed architecture could track phobias (also known as negative engagement in virtual reality literature). Where people encounter phobias near architectural points in time and space, their negative phobias can be visibly recorded and aggregated. The digital model could be 'sprayed' with an aggregated spray of phobia colour. We note here it may be difficult to aggregate phobic areas or even locate the spatial or symbolic phobic triggers. Furthermore, trained psychological help may be required to create, calibrate and adjust the environments as well as ensure that the test environments pass ethical and medical clearance and are used safely and effectively.

Conversely, positive engagement could also be tracked: significant points of interest (indicated by pauses, and by heightened or lowered rates of biofeedback, and perhaps camera tracking of postural change, or tracking of eye gaze) could be recorded.

Finally, filtering environmental detail through biofeedback may both virtual and augmented reality projects, such as lifeClipper (Torpus and Bühlmann, 2005). Through the head mounted display, participants saw vague and coloured video characters as they walked through Basel, but through oddly shaped stencils. Biofeedback could have affected the perimeter and clarity of the augmented reality objects, the calmer the walker; the higher the resolution clarity or viewing window of the augmented display object or video. This project also featured pressure sensors incorporated in soles to wear in one's own shoes for tracking walking behaviour, but it could also be used to augment the excitement level in the augmented environment.

At a simpler level, biofeedback can be used to affect territorial awareness, for example, more excited states could increase or diminish the field of view, and this could have significant benefits for large-scale projected environments such as CAVE UT.

Methodological issues

Are there currently accessible, effective and accurate devices to measure biofeedback? What can we measure, react to, and creatively leverage when implementing individual and group biofeedback, which are appropriate to the architectural domain? Are there any advantages or disadvantages to the use of biofeedback and can we ascertain them by trial evaluations?

The following products, Neurosky, Emotiv, and Wild Divine have been selected as the most accessible and widely used biofeedback devices for recent virtual environments. For the sake of simple architectural experience tests, we argue that biofeedback can be applied in terms of understanding the self, the environment, or other (fictional or real) participants' reactions to the environment. However, the variety of responses possible, the lag, the calibration required, and the indirect and vague nature of the biofeedback have convinced us that for architectural testing purposes it would be difficult to conduct tests using biofeedback to ascertain architectural empathy of form or material.

Secondly, we suggest that indirect biofeedback used to increase the sense of trepidation or excitement of the environment is best employed in games (or perhaps in social worlds), however there is potential to assess serenity and contemplation in sacred spaces. Thirdly, using indirect biofeedback to personalize the environment and recognize the attitude through physiological state of others is interesting, but difficult to evaluate in smaller test environments of shorter duration. For measuring subjective responses, using a control group to test comparative results in task performance does not seem appropriate.

Architects may be more interested in whether participants find the modified environment is more responsive (in a positive way), with more character, more appropriate to what is simulated, and more interesting. They may also be interested in whether the modified environment has a more engaging sense of territoriality. For example, changes between calm and excited biofeedback states could affect the field of vision and the lighting condition. Finally, the participants could also be asked which of these biofeedback-influenced factors have the most natural mappings (i.e. the interaction metaphors are most appropriate).

Conclusion

What is innovative about biofeedback applied to architecture and why is it significant? As far as we know, there is no convincing and through review of how biofeedback, and indirect biofeedback in particular, can be usefully applied to architecture. While there are increasing numbers of papers on biofeedback applied to games, such research must be critically reviewed before being applied to digital architecture, for the two fields differ so greatly.

This paper explored the imaginative and atmospheric use of real time biometric feedback within interactive digital environments but particularly for architecture. We suggest five main areas of applications for the above type of biofeedback (indirect biofeedback based on changes in physiological states) for digital architecture. Participants could indirectly colour their surroundings, which may afford them more insight into the world around them, their interactions with it, or the progress and experience of other participants. In terms of object creation, more uniquely personalized and engaging environment elements (also known as externs) could be directly or indirectly created from biofeedback. Atmospheric-affecting biofeedback may augment and enhance a sense of inhabitation. Biofeedback could also be used to contextually filter and display information so that a user is not overloaded with extraneous information, or, conversely, observant and more empathic participants could be rewarded with more information. Indirect biofeedback could also help tracking of participants (of phobias – also called negative engagement – and positive engagement).

These ideas may be of interest to those keen on creating more engaging virtual worlds, those interested in whether digital simulations can better approach the richness of real world places, and those curious in indirect interaction metaphors for experiencing places. Biofeedback may help those who wish to create not just simulations of religious, revered and historic architectural sites, but those who also wish to convey a sense of the experience of various audiences who have visited them.

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