Maxwell's Demon: A Study in Brain-Computer Interface Game Development

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ABSTRACT
In this paper, we describe our development of a testing environment for determining the efficacy of brain computer interface (BCI) devices and their role in the future of computer video games. Using the Blade3D engine from Digini, inc. and the NeuroSky Mind-kit head-mounted EEG device, we have created a game, titled *Maxwell's Demon*, which attempts to determine if a BCI device can be effectively implemented as an active controller in gaming. Additionally, we have developed in-game methods to determine what auditory and visual distractions can interrupt BCI communication. By including a recording component to our game, we have the ability to capture the player's levels of concentration and correlate that data to screen captures, determining areas of difficulty for possible use in level development and testing.

Categories and Subject Descriptors
H5.2. [**Information interfaces and presentation**]:User Interfaces.
I.2 [**Artificial Intelligence**]: Cognitive simulation, Philosophical foundations, Games, Analogies.

General Terms
Algorithms, Design, Human Factors.

Keywords
BCI, Brain-Computer Interfaces, Games, Multimodal Interaction.

1. INTRODUCTION
For years BCI devices have been used for physiological imaging and monitoring. While research is ongoing in the medical field to make BCI systems faster, more accurate, and less evasive, the video game industry has looked to BCI as a possible controller device. Other than EEG and fNIR, the other brain monitoring technologies are not plausible for use in a consumer product due to their size and expensive nature (Bunce, 2006). However through lower cost, portability, and availability EEG and fNIR-based devices have become a realistic possibility for BCI controllers (Oum 2008).

2. LIMITIATIONS OF BCI DEVICES
Because BCI devices differ from current video game controllers, BCI games cannot be developed in the same way traditional games have been created. Depending on the type of BCI device used, certain biofeedback limitations must be taken into account to receive reliable readings.

2.1 fNIR Device
The fNIR device (pronounced 'ef-near') projects infrared light into the frontal lobe of the brain and determines oxygenation levels. These oxygenation levels correlate to the user's ability to concentrate. A 5 to 8 second delay occurs between the time the fNIR gathers and reports data. In this situation a game developer would need to take this factor into account when designing their game. This makes it difficult for events that require immediate action to be used by the fNIR. For example, if the player needed to dodge an object coming toward them, it would be problematic to use this BCI device to control player movement because of this latency issue. For this reason, multimodal games, games which use more than one input controller, allow the game developer to mix traditional game play mechanics and new mechanics specifically for the BCI device.

Additionally, the data that is reported from the fNIR device must be averaged to determine a normal relaxed state on a per user basis. The relaxed state value of one user will not be the same for all users. The procedure for acquiring a baseline value involves the user staring at a black screen with a cross at the center. The fNIR then reads the values of a relaxed state and saves this information to determine when the values rise above or go below this baseline value. A game developer would need to somehow incorporate this procedure into the game design.

2.2 EEG Device
An EEG, or electro-encephalogram, device records the electrical impulses in your brain through small metal electrodes placed on your scalp. Specifically, our team used the NeuroSky head set device which detects brain wave patterns and uses gyroscopic sensors to assist latency readings of the EEG. NeuroSky has developed their *Mind-Kit* which includes both hardware and software algorithms which can interpolate brain readings into two emotions, "attention" and "mediation".

While the NeuroSky device provides real-time data values, our development team encountered communication issues when the user was not still. The head set relies on the 3 main disc sensors, which two are placed at the base of the skull and one on the forehead. If the user was to move their eye brows, it was common for the head sensor to lose connection, causing an error or spike in readings.

Because the NeuroSky detects electrical signals, nearby equipment could adjust the values inadvertently, commonly referred to as "noise". This presents potential difficulty considering the computer running the software itself could affect the gathered values. However, our development team did find the NeuroSky to be user-friendly and considerably reliable in its readings.

3. RESEARCH HYPOTHESES

3.1 BCI as an Active Controller

The development team would like to determine if BCI devices are the next potential step in video gaming controllers. While hardware manufacturers have developed small demos to showcase the devices capabilities, few actual games have been released. Through *Maxwell's Demon* our group would like to investigate if BCI devices are comfortable and reliable enough to be used as a main control scheme in a video game.

In *Maxwell's Demon*, the first hypothesis is repeatedly tested via platform manipulation. The player must use the device to control the directions of movable platforms. Because mild headaches have occurred while using the fNIR device, we hope to discover if length of play has a physical effect on the player.

3.2 The Role of Distractions in BCI Gaming

In *Maxwell's Demon*, we present the player with the specific task of exiting a room. In more advanced levels, we present auditory, visual and physical distractions as an attempt to affect the player's levels of attention and meditation.

If we can determine what types of distractions throw off a player's ability to stay focused, it would allow us to gather valuable information that could have an impact on how the game industry play-tests its games. Determining what distractions affect BCI game play also has the benefit of knowing what real world distractions would have an effect on players. Since the device is measuring a user's ability to concentrate or meditate, would the real world setting affect the player's performance? In settings like game competitions, would environmental background noise affect a player's ability to succeed in a BCI developed game?

3.3 Detecting Frustration Using a BCI Device

Imagine the value of knowing when a player is having difficulty in a particular area of a level. The potential to adjust the difficulty based on the user's brain information and not rely on the player having to explain the difficulties their experiencing would be a major benefit to how games are tested and developed.

While the NeuroSky device has specifically been developed to detect levels of meditation and attention, and the fNIR can detect levels of concentration, our team was interested in determining if a BCI device can detect frustration levels. In order to accomplish this task, our team developed a data analysis program that records BCI values while simultaneously capturing video game play. Our goal is to find patterns of values that consistently appear when a user reaches a near impossible task.

4. TESTING ENVIRONMENT

4.1 Development in Blade3D

Our team chose Digini, Inc's Blade3D engine to design our research environment. Blade3d is a new game engine, officially released in Jan 2009, which was specifically built to allow anyone to design and produce a working game that could be deployed on the PC or XBOX 360 regardless of programming experience. Blade3D uses a graphical node interface that provides budding developers the ability to choose snippets of code and connect them to other graphs. Blade3D is built on C# programming language and does allow experienced coders to write their own scripts for game development.

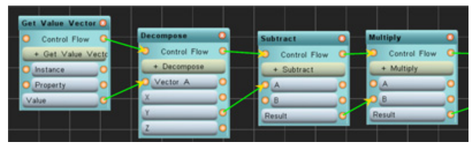

Figure 1. Digini's Blade3D game graphs.

By utilizing the ability to write C# components that can interface to the game engine, our team's programmers designed a link between the NeuroSky hardware device to read in specific information that the device was collecting from the user's brain wave patterns and utilize that information within the game engine, specifically values of "attention" and "mediation" (see figure 2).

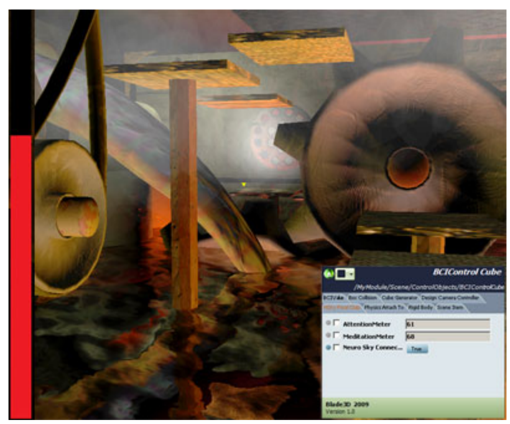

Figure 2. *Maxwell's Demon* BCI Meter and readings.

4.2 Game Design

Maxwell's Demon is a first-person perspective puzzle game that allows the user to manipulate the environment to clear various hazardous rooms. By harnessing the power of brain-controlled devices the player will be able to position floor tiles using levels of attention and meditation in order to move from the entrance to the exit of the room without being harmed by environmental hazards. In-game auditory and visual distractions present secondary challenges that attempt to interrupt BCI communication between the player and the game.

The main focus of the development of this game is research into Brain Computer Interfaces and their role in video gaming technology. Therefore, our main concern is validating our three proposed hypotheses (see Section 3). However, providing an entertaining experience to the player is also a very important factor in game design, and a failing to provide an adequate story could cause extraneous results from our research. For example, if the player becomes bored, could the BCI readings be affected? Therefore, our development team created a storyline for *Maxwell's Demon* in the interest of proper research and entertainment based gaming.

4.2.1 Game Story

The story takes place in both the game's "reality" and within the mind of the player character simultaneously. All game play events exist within the mind of the player character. By creating a story that allows the player's imagination to be the setting, it allowed certain creative freedom for our team to develop rooms with variety, but staying consistent within the defined specifications.

After suffering injuries from a serious car accident, the player has been hospitalized and placed in a drug induced coma while surgeons attempt to revive the player. Unknowingly to the player, they enter a dream state, conjuring up the world of *Maxwell's Demon*. The player wakes up inside a fantastical machine powered by steam and the motion of its own actions. Trapped inside menacing rooms, it becomes clear that the player cannot stay in one spot and must find exit or surely perish. Each room the player enters becomes more difficult and frustrating then last, mimicking the struggle in the real world as his/her life hangs in the balance. Suddenly, the player discovers that they have control of this environment. The ability to move platforms with their thoughts begins to shed new light on this strange new world. Finally it is clear, that the player must summon all of their brain's power in order to escape the contraption known as *Maxwell's Demon*.

4.2.2 Level Design

The assets created for *Maxwell's Demon* were designed with the ability for them to be re-usable and translated to easily develop new levels. For instance, simply by changing the layout of the platforms, a researcher or designer has the ability to create new rooms; thus, adjusting the difficulty of the level. Additionally, the use of audio and visual distractions can be hand selected via an options menu, which allows the researcher to choose what type of distraction they are interested in experimenting with.

Each level that was created serves a purpose in answering our hypothesis questions. The first level named *Sewer Room*, contains a minimal list of actions required by the player. Developed as an introductory level, the player simply needs to cross the series of platforms, concentrate on a moveable platform and place it in the missing section. This allows the player to become familiar with the Xbox 360 controller and the brain device feedback information before we bombard them with physical or auditory distractions. The *Sewer Room* is our attempt to determine if current BCI technology is ready to be used as an active controller. The development team was interested in how well a traditional gamer could adjust to using a head mounted device and if player performance depended on the individual or if it was consistent among users. Additionally, the *Sewer Room* can be made more difficult by employing distractions from the options menu.

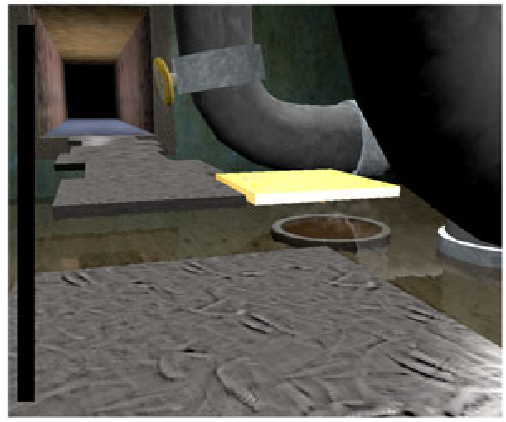

Figure 3. *Maxwell's Demon* Sewer Room.

The second level in our game is called the *Machine Room*. In the *Machine Room*, the player is faced with physical obstacles (moving platforms, swinging hammers), and is required to move two platforms into place in order to clear the level. This second level challenges the player to perform under a moderate level of stress because timing movements is vital in completing the level.

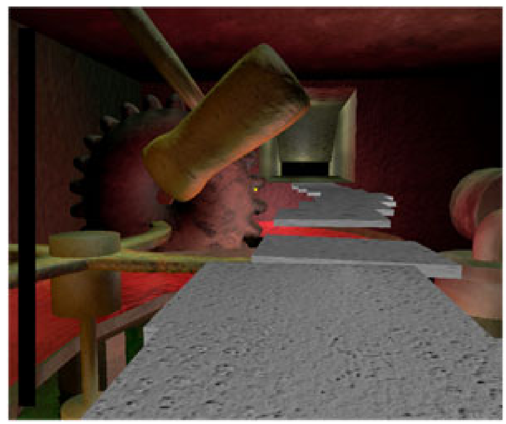

Figure 4. *Maxwell's Demon* Machine Room.

In the third level, named the *Steam Room*, the player is faced with various types of distractions simultaneously. The player has a total of four brain controlled moveable platforms, four autonomous moving platforms, visual distractions including bursts of steam and disorienting lens effects, auditory distractions in the form of fog horn blasts, and physical challenges including jumping from heights surrounded by poisonous oil pools. This level is our attempt at bombarding the player with as many types of distractions as possible.

Figure 5. *Maxwell's Demon* Steam Room.

The final level of *Maxwell's Demon* is our attempt at trying to discover patterns in our data that represent frustration. While the level design is very simple, similar to the first level, we have removed the normal mechanic of moving the platform via the BCI device making the level impossible to clear. The level is designed to calm the player, utilizing soft blue lights and animated cartoon whales that jump softly into the air. The design of the room has a marionette style that differs greatly from the previous levels. Soothing sounds of whale songs accompanied by laugh tracks have been developed to frustrate the player further.

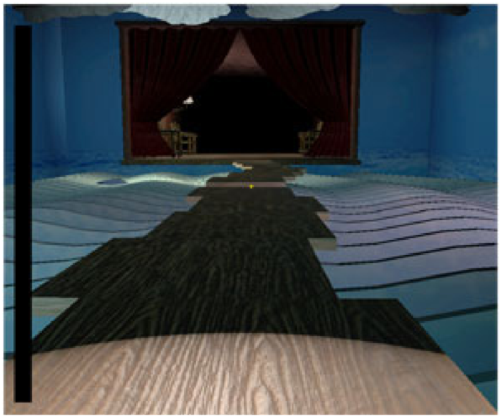

Figure 6. *Maxwell's Demon* Whale Room

4.3 Data Plotting and Analysis

In order to visualize and analyze our data, we have created an Adobe Flash based review application. Our team's programmer developed a C# component that reads the BCI data values from Blade3D and writes them to an XML file that can then be read in by Flash. We use this data to plot a line graph that shows how attention and meditation levels vary and accompany this graph by in game video capture using CamStudio, a free screen capture tool. CamStudio has the ability to record screen data directly to SWF file, Adobe Flash's native published format. Small file size and web browser compatibility make this feature beneficial to our project because this data can easily be displayed on the internet and shared with other researchers. The Flash application also has the ability to read when a distraction has been triggered so researchers can correlate the change in BCI values to the specific distraction.

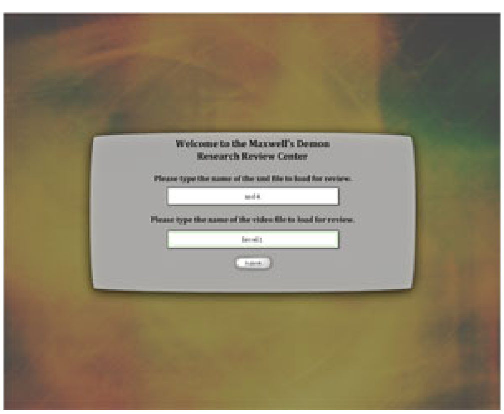

Figure 7. Review Application Main Screen

This tool is completely automated so a researcher without game development or Actionscript programming experience can use it. Once the video screen data has been captured the researcher just needs to put the video file in the corresponding folder and move the Blade generated XML file into its folder. The researcher then just needs to specify the file names on the Research menu screen to view the captured data. We believe this tool to be extremely beneficial to researchers in other fields of BCI who are interested in their applications in game design.

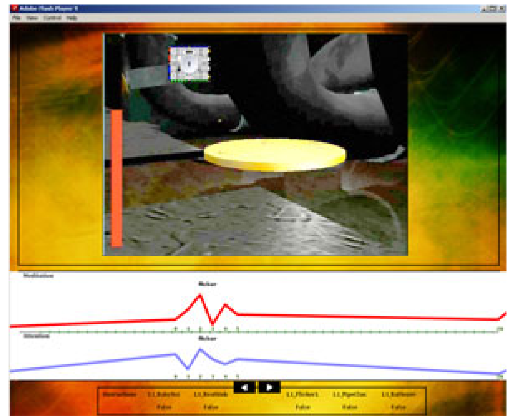

Figure 8. Review Application Data Screen

5. FUTURE WORK

BCI based game design is on the cutting edge as the hardware becomes more affordable and user-friendly. Our main goals in this research study were to generate a testing platform that is engaging and educational in BCI to videogame development.

As BCI technology becomes more advanced, the potential for video game playtesting with BCI devices becomes more of a reality. If a game development company was to use BCI hardware on its playtesters, they would have access to the raw data of the player's mental state while they are playing their prototypes. This information has economic benefits in that changes to the game before releasing it to the general public could help the game to sell to a wider audience.

BCI devices and game development can also span to other non-related fields, specifically the medical community and Attention Deficit Hyperactivity Disorder. The ability for a person with ADHD to sit down at a game console and solely focus on the required tasks, but unable to concentrate while in school is an interesting phenomenon. With a BCI device that measures concentration levels, games could be created with the sole purpose in understanding this phenomenon and possibly generate new findings and treatments.

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