Inducing Targeted Brain States Utilizing Merged Reality Systems

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***Abstract*—As virtual reality becomes more accessible and the technology becomes greatly improved to immerse the individual in real time, there will be an impact upon the human brain and its direct functioning over states of mind. For as long as humans have noted that the brain responds to lights and sounds to aid or alter moods and mind states, technology has been used in one way or another to induce some desirable mood. This paper investigates how virtual technology could be used to forward this idea.**

Keywords—Virtual Reality (VR); immersive; sound light machines; entrainment; brain waves; auditory / visual stimuli

I. Introduction

It has long been known that the human brain can be influenced deliberately to achieve specific states verifiable by observing EEG (Electroencephalography), MRI (magnetic resonance imaging), MEG (magnetoencephalography) and NIRS (near-infrared spectroscopy) scanning devices. These states manifest in everyday life as moods, sleep or arousal of varying degrees. Ancient philosopher-scientists such as Apuleius (around 125 C.E.) and Ptolemy (around 200 C.E.) both experimented and studied the phenomenon of the ability of flickering lights to induce altered states in the watcher [1][2]. It is obviously possible to go even further back than this to relate the use of sound as an instrument to achieve the same end with shamanic practices involving rhythmic musical patterns.

In more modern times, scientists and visionaries have explored this phenomena as technology has developed. For example, in the 17th Century the Belgian scientist, Plateau, used a strobe wheel to explore the diagnostic significance of flicker fusion. His experiments revealed that as the strobe increases in speed the light will become a single persistent un-flickering light source to the observer. In healthy individuals the flickering was visible at much higher frequencies. More recently it has been found that long term meditators can separate individual flickers at much higher frequencies than non-meditators [3].

Also, at the turn of the 20th Century the French psychologist Pierre Janet observed that patients at Salpetriere Hospital in Paris became more relaxed and had reductions in hysteria when exposed to flickering lights [3].

II. Sound and Light Machines

This effect was further investigated as both interest in observed mental states and accompanying technology developed. As EEG and other systems of allowing the states to be quantified and visualised became prevalent, it became easier to see what directly altered the brain's electrical activity and how these matched its various modes. Table 1 gives a basic idea of the related predominant brainwave pattern and associated state. Much work has been done in this area with imaging, as scanning technology has improved [4].

The noted effect of brain entrainment, seen singularly in light and sound, when combined, deepens the overall impact of the immersive experience. Technology was developed from experiments in consciousness and psychological research to become small handheld units from the 1970s onwards. These units use the entrainment visually and auditory by synchronizing the flicker of light and the playing of sound at known frequencies which cause the dominant frequency in the brain's EEG to become locked or induced to a specific target for periods of time.

Further to this, another effect, now known as binaural tones or beats, was found by Heinrich Wilhelm Dove in 1839 [5]. When a tone is played in each ear but separated very slightly in frequency, a tone is apparent to the listener depending on the difference. For example, in the case of a 300Hz tone in one ear and a 310Hz in the other via headphones a beat frequency of 10Hz is formed. This beating tone, known as the binaural beat, will be perceived as if occurred naturally without the individual tones to each ear. The dual tones must be below 1000Hz for this effect to be heard by the listener. Also, the separation should be no greater than 30Hz between them or the tones will be heard separately and distinctly.

It is this produced frequency, or beat, that enhances the "frequency following response" or entrainment. At any given time the human brain can produce a dominant electrical brain wave frequency. Other frequencies are also present but one will largely be in place revealing something of the brain's overall state or mode.

Other methods have been noted which include using monaural beats and isochronic tones. Binaural beats are formed by the brain's own creation, monaural beats occur externally.

The binaural beat is formed in the brain by the neural output from the ears and created within the olivary body in an attempt to find the location of the sound based on phase. In the case of the monaural beat this is formed by the adding or subtracting of the two waveforms as they interact, effecting their amplitude, becoming louder and quieter in a cycle. Both binaural and monaural beats rarely occur in nature but frequently in the human and mechanical worlds. For example, where multiple engines run at slightly different speeds in aircraft or suchlike, the vibrations from both meet in the surrounding area or deck. The lower tone is known in this case as the carrier, whereas the upper is known as its offset.

When two different guitar strings at slightly different frequencies are plucked at the same time the resulting waveforms hit the ear as monaural beats and excite the thalamus in the brain, which in itself is part of the entrainment process. If a binaural beat is heard through speakers it becomes a monaural beat, thus requiring the direct separation afforded by headphones to be properly re-created. An interesting aspect of these beats are that monaural sounds are dependent on the two tones being the same amplitude level whereas the binaural methods are not affected by this. In fact, one of the tones can be outside the hearing threshold. Introducing noise to monaural beats will degrade them while binaural beats become more prominent.

Isochronic tones are widely regarded as the best tone-based method for brain entrainment and elicit a strong cortical response [6]. Where an individual doesn't respond as well to binaural beats they may respond better to isochronic tones which are most effective using headphones. An isochronic tone can be defined as evenly spaced beats of a single tone which are repeated in what can be rapid succession. They are sharp, distinctive tones that rise to full amplitude and back to nothing. Like monaural and binaural beats, the isochronic tones can be either embedded in music or left in its pure form to the listener, though this can be unpleasant [7].

The concept here is that a stimulus frequency produced by the binaural technique which lays in the range of the brain-wave frequencies makes the predominant frequency of the brain move toward it. Various attributes of brain functional seem to be affected by this, including spatial perception, stereo auditory recognition and also the activation of many sites in the brain. Again this stimulus does not have to be purely auditory, it can be visual or a combination of both; the frequencies involved being the same in range as noted previously.

A sound/light "mind" machine, combines the effects noted above and has been available for some time commercially. For example, the Procyon [8] produces sequences of variable light and sound pulses to specific programmes both built in and user defined. The sound and light characteristics and duration are variable and programmable. It is possible to create washed out fields in the user's vision (a true Ganzfeld effect, from German meaning "complete field") or shimmering cascades with matching audio sound track.

TABLE I. IDENTIFIED PREDOMINANT STATES AND ASSOCIATED MENTAL CONTENT

Frequency range	**Name**	**Related attributes and states:**
> 40 Hz	Gamma waves	Higher mental activity, perception, problem solving, fear, and consciousness. Appears in specific meditative states, relating to Buddhist compassion meditations in the Tibetan tradition.
13–39 Hz	Beta waves	The most usual state for normal everyday consciousness. Active, busy or even anxious thinking. Also appears in active concentration, arousal, cognition, and or paranoia.
7–13 Hz	Alpha waves	Relaxed wakefulness, pre-sleep and pre-wake drowsiness, REM sleep, dreams and creative thought or free association. Considered as the brainwaves of meditation. These waves also appear in the relaxation process before sleep.
8–12 Hz	Mu waves	Sensorimotor rhythm, Mu Rhythm.
4–7 Hz	Theta waves	Appears in deep meditation /relaxation, NREM sleep. Also, in hypnotic states or where some element of consciousness. A theta prominent individual may be awake but lose their sense of bodily location, for example.
< 4 Hz	Delta waves	Deep dreamless sleep with loss of body awareness. Does appear in the EEG of very experienced practitioners of meditation and would appear to relate to some ecstatic states. Maintaining consciousness while delta present is difficult.

A complete programme will have an overall aim such as "meditation" or "learning stimulation" but the actual programme may wander through several frequencies for varying durations to get there.

The newer mind machine, Kasina, again from Mindplace [9], has even more expanded capability. As well as sound synthesis built in for the audio pulse tones it also incorporates sample player technology to play music or environmental sound tracks which have embedded frequency encoding.

A technique used by the Kasina, as well as by light and sound frequency pulsing is that of music modulation. Any part of playing music could, in theory, be modulated in such a way so that binaural or monaural frequency following response is initiated. For example, it would be possible to modulate the bass track only of a piece of music using low pass filtering to select that band and thus avoid distorting other components that lay within the soundscape. A binaural beat can then be developed using modulation techniques. The Kasina contains many such tracks from soundscapes based on the environment, from rainy forests through to shamanic drum patterns and Tibetan bowls.

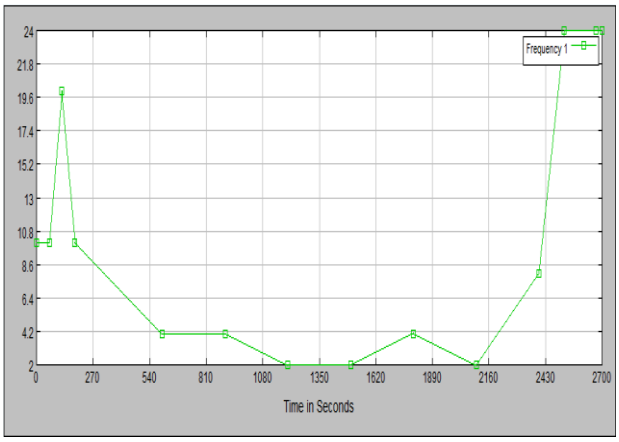

Fig. 1. Showing light frequency for program in Kasina

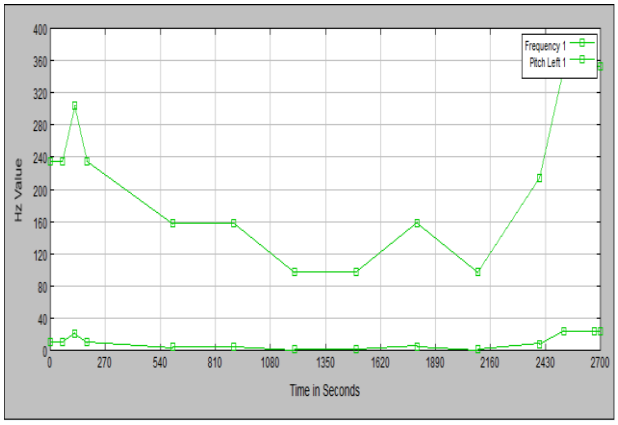

Fig. 2. Showing light frequency in relation to audio for program in Kasina

In figures 1 and 2 present a program for the Kasina which attempts to induce a "meditative state" that is, the brain waves produced exhibit properties to what the signature would look like for an adept meditator. In this case, the light frequency has an initial burst, to stimulate. The waveform then drops in frequency steadily, until the lowest point is reached of just 2Hz, which is actually classed as delta. After some time in these lower frequencies the waveform steadily climbs again. The entire session in this case being 45 minutes.

III. VECSED – Virtual Environment for Control, Simulation and Electronic Deployment

Immersive media systems, such as virtual reality worlds offer environments in which an individual can be placed in a totally controlled situation. To expand the capabilities and interface more thoroughly with the outside world, the system used in this project is VECSED[10].

VECSED has the ability to stand between worlds, that is, VR and real life, and coordinate communication streams to devices, controlling and providing information as required. This is shown in figure 3.

For example, in brief, it is possible to control a virtual device from the real world or vice versa. The server in the system provides a look-up service to available resources in its network. The VECSED system stores the following information about any given agent or device connected to it:

- Name of the agent
- IP address and port for communication
- Type of resource
- Hostname, if relevant
- The last communication time
- Geospatial information such as longitude and latitude

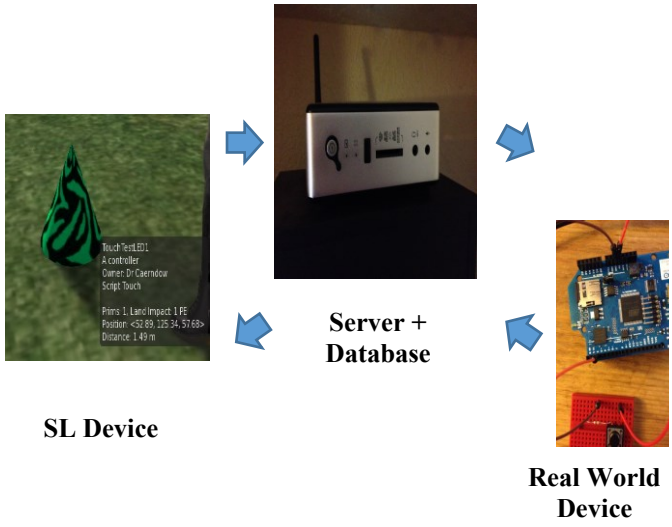

Fig. 3. Flow of information between worlds

When a device boots or, instantiates itself, a security procedure authorises its presence on the merged reality system and it becomes registered. The various agents on this network can then enquire for particular resources either virtual or "real".

In this project the idea for VECSED is to provide a seamless communication between the EEG device and the virtual world. In effect, it provides the biofeedback loop and allows for further experimentation in the sense that more devices could easily be added for actual control or stimulation, the basis of a brain computer interface (BCI). This particular project will focus on the capture and adaptation of the virtual environment in response to the EEG pattern.

IV. NeuroSky EEG

Recent innovation of faster processors and interconnecting network technology allow for capture and processing of brain information in real time, efficiently and without the need for vast arrays of equipment, wiring or external software processing.

The NeuroSky Mindwave Mobile [11] is a research grade EEG reader based on the TGAM (ThinkGear ASIC Module) bio-sensor chipset featuring a Bluetooth interface and software to capture data. Various software are available to record or visualise the current state of the user. It measures the power output of the various bands such as alpha, beta, gamma etc. and specific qualities such as attention and meditation as well as eye blink. The device consists of a headset, an ear-clip, and a sensor arm. The headset's reference and ground electrodes are on the ear clip and the EEG electrode is on the sensor arm,

resting on the forehead above the eye (the FP1 position). It uses a single AAA battery with 8 hours of battery life.

Typical software available includes both desktop varieties and phone apps. They range from recording and visualisation of the brain EEG pattern to some interesting BCI type control and biofeedback. For example, one application plays movies and alters the storyline depending on the brainwave output. Another allows the user to attempt to enter a meditative state and responds by a ball rising on the screen – the height attained equalling the period spent in a characteristic meditative state. Similarly, another application measures attention span graphically and somewhat originally, by the on screen object erupting into flame for the period of held attention span.

A. Utilising the EEG device with VECSED

Although there is a large range of software available for the headset, it was necessary, for this project, to write a lower level interface to gain access to the raw and semi-processed data directly. This data stream leaves from the headset via Bluetooth and is picked up by the desktop computer by specific drivers and then processed by the custom software developed for this work. The data available from the headset came in the ranges of low alpha, high alpha, low beta, high beta, low gamma, high gamma, delta and theta. As well as this there are two uniquely calculated eSense™ values [12], named meditation and attention or focus.

The advantages in using a 3D world for purely some kind of induction or control of brain states are really about immersion. While brain entrainment machines are "dumb" in some senses of the word they are effective. Combining the Ganzfeld effect [13] [14] and accompanying stereo audio fields offers an inescapable (in terms of distraction) immersion for the user and is therefore very efficient.

Software was developed to intercept the data stream from the headset and was linked into the system as a separate communicating process, in the same way as other objects that wish to become part of the network. This process, once initiated, communicates with the central server which checks its authenticity and registers it as any other virtual or real device would. Any other object now knows this asset is available and can exchange information with it. In a similar way, the headset software object can make available its data stream to any other device, virtual or otherwise. Figure 4 shows the basic information flow between the various components.

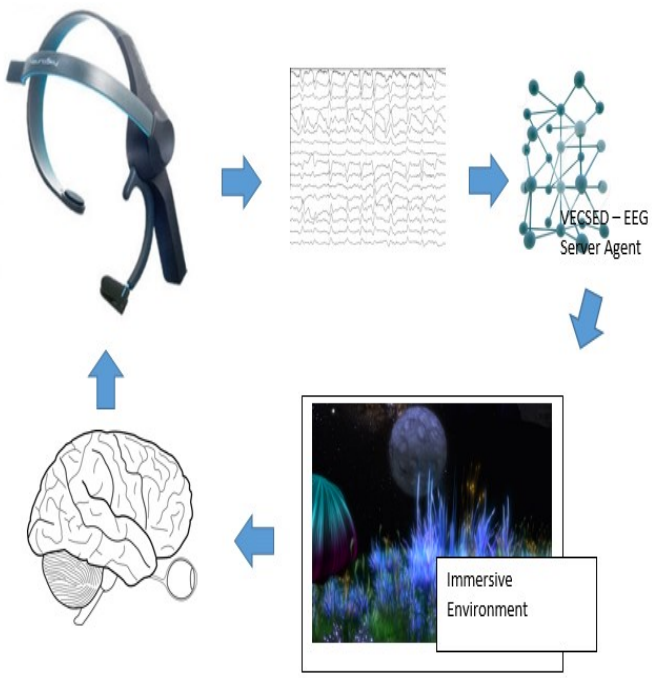

Fig. 4. System diagram showing feedback loop between adaptive environment and user

V. COMBINING THE TECHNOLOGIES

A. Virtual world responds to EEG

This stage was to test how virtual objects can be made to respond to the output brainwave patterns. An EEG server was created to handle and process the data stream, it was from here that devices virtual or real can be activated depending on particular waveforms.

A simple 3D EEG display was created in the virtual world Second Life (SL) [15] showing the current output. This consisted of bars which grew in size depending on how much of a particular waveform was present. Very little network lag was visible. Separate objects in SL received messages regarding the value of each appropriate waveform and reacted accordingly for alpha, beta, gamma etc.

The next stage was to experiment with meditation and attention output as recognized by the software. A 3D ball was created using particles which expanded in size as one of the attributes increased – blue for meditation and red for attention.

An experiment was created of two 3D animations, one being complex in nature, showing a flow of 'mechanical' objects in progression, the other more liquid and surreal (using the particle type in SL). These activated when the person's avatar touched them. Once activated and stared upon there was a discernible effect on the output and the ball could be seen to be dominated by attention type wave form or more meditative for the surreal abstract form.

B. Biofeedback

A more elaborate experimentation was necessary to explore the simple findings of the above. The main point here being the idea of immersion and control.

Immersing the viewer in an environment which reflects the current user is one way which this system could be used, the other is to use the environment to gently lead the individual to a more useful or target state. The former should still be investigated first as an exploration to inform the latter, which is the main subject of this paper.

C. Reflections

A palette or repertoire was made available to the main system process that was linked into VECSED. This was grouped into visual and audio within the 3D domain. To simply reflect the users EEG state appropriate correspondences were made between this palette and the modes of the EEG.

A "pull out lab" was created within the virtual world. When instantiated into SL, the lab builds up the controllable environment pod and associated tools such as the virtual process devices which communicate via VECSED. The palette process could change the colour of the environment, media output to walls, audio, or more complicated objects necessary for an environment. The word "scene" is used to identify a particular set within the palette representing a specific mental state visualised in the EEG.

With the avatar standing within the environmental pod, the user wears the EEG device. This then feeds the signal and is processed by VECSED. In the virtual world the pod's processes access the palette and, depending on programming parameter, selects an environment which reflects the incoming data stream relating to the user's brain wave pattern. The following in-world modifications were tried:

- Color of environment
- Texture of environment
- Images and played media of environment
- Sounds

As well as combinations of the above.

D. Manipulation of mental states

These can be further grouped by "scene". Here scene is taken as a specific set of visual and audio cues to induce, or part induce a step toward a brain state. For example, a scene to bring about concentration may involve the user stepping on bricks in sequence or concentrating on objects merging.

It can be seen how in the above experiment the system can be made to reflect the user's predominant EEG pattern and therefore a fairly accurate representation of the mental state. It can now be considered how it may be possible within immersive virtual environments to manipulate a person's mental state, or attributes.

In the reflection exercises a palette was developed to signal when a state is reached; here, particular scenes or sets of these are used to induce steps toward a goal, if possible. As well as these, more complex "task" objects were created:

- Concentration object (tasks involving stepping, counting or focusing)
- Meditation object (abstract, soothing, tending toward "hypnotic")

The concentration object is basically a set of tasks that are instantiated on demand; stepping stones, target focus or calculation. The meditation object included elements which were much more abstract in type, relating to sounds and textures.

E. Integrating known inducing agents

From the history of this area (noted above) there are known to be several agents which can affect the user:

- Stroboscopic elements
- Ganzfeld lighting effects
- Synchronized audio patterns (monaural, binaural and Isochronic beats)
- Embedded audio patterns (modulating elements of a soundscape or music track, not obvious to the listener)

The virtual world of SL is complete enough and capable of being programmed [16] to contain any or multiples of these. The environmental pod was made so elements within its structure could be made to pulse in particular ranges, or emit a Ganzfeld light effect to blanket the user's field of view.

Sound in SL can be mono or stereo and takes two forms, as samples (or clips), or incoming streams. An object was created to act as an audio interface. This stored basic audio pulse patterns for various ranges, soundscapes and music with embedded modulation. The audio control object in effect stores samples so can hold practically anything. This mechanism for sound only allows small samples which is enough for basic sound loops – particularly cyclic tones. A more complex mechanism was created to allow for longer media. This involved streaming the sound in, as required from a server which stored the appropriate asset (sound, video or other media). The assets were stored on the server in a database allowing for a complex library. The controller for the environmental pod simply requests the resource when needed and the media arrives as a stream, ready for rendering or playback.

The surface of an object can be controlled in a basic sense in SL, given an image as its texture or pointed at a resource such as a video clip to form a screen. Other attributes can be given too. It can be made a colour, be "bright" or reshaped and sized. When combined with the ability to put the basic prims (basic building blocks in SL) together and incorporate scripts

in any for activation, this offers myriad opportunities to add our inducing factors noted above.

Given these capabilities, the created virtual environment pod becomes a light and sound synthesizer capable of being reactive to the user's EEG and also influencing it in a true biofeedback loop.

F. Patterns and programs

It is possible to form sequences which will take a user on a journey to a state where a waveform predominates the EEG stream, although at a given time there are a number of contributing factors which make any one user susceptible to one particular pattern.

A simple programming language was created to control facets of the virtual environment. At its most simple a program could be made to load a scene and cycle until a given state is reached, an example is shown in figure 5.

```
// instantiate scene "focus ball" and initiate animation/sound
// sequence
load scene "focus ball";
repeat
  // set initial ball state
  scene element["ball".message["blue"]];
  // wait until the incoming EEG stream predominantly what
  //  is required
  wait until eegstream(WAVE) == BETA;
  // State achieved set ball to red
  scene element["ball"].message["red"];
  wait until eegstream(WAVE) != BETA;
until FINISH;
```

Fig. 5. Simple initial feedback loop with system

G. Initial tests with the full system

The full system when running identifies the predominant EEG wave pattern and adjusts the environment to reflect this, in the way described above. The user can initiate a scene which attempts to create the steps leading to the target state.

Only a small sample of individuals were tested – the focus in this project being to develop the technical side, and with this, ensure it is likely to prove a suitable environment for experimentation. The results did show that individuals can be induced fairly easily into both focused and meditative states, particularly in immersive environments. Often the case being that it isn't so much the induction into a specific state but the stabilisation and maintenance of it.

A few points can be noted here from the practical usage of the system. It is often the case with the NeuroSky EEG that results will only be correct when a good earth connection is formed via the ear clip; oftentimes if this is not initially damped either no connection is created and thus no signal or erroneous data is gathered, presumably from "floating connections".

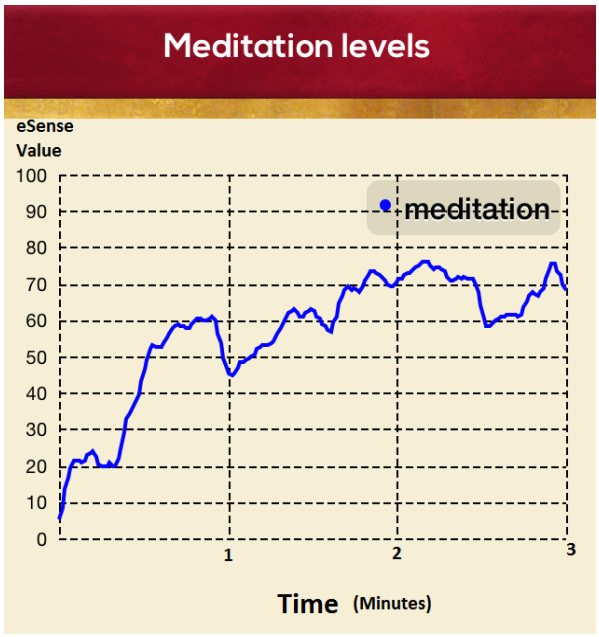

Fig. 6. Showing initial induction into "meditative" state after 3 minutes

The eSense™ values are very stable, calculated on the ASIC chip from an algorithm which does not appear to be disclosed. They seem to be very accurate at deducing both focused and meditative states and it would be interesting to see what the "signature" of the various waveforms is, which is specific to these. It is known, for example, that the characteristics of some types of meditation vary to others in terms of predominant waveforms produced. Alpha predominance has been shown as the typical waveform present in various forms of meditation such as TM (Transcendental Meditation) and Zen. However, the gamma waves appear to present in particular types of meditation regarding compassion, holism or synergistic practices.

VI. Future Scope

The system showed it is possible to integrate various technologies into a merged reality system, in this particular case the beginnings of exploration of a BCI with biofeedback applications. VECSED showed how capable it is at acting as a communication mechanism between processes which are both real and virtual. It would not be difficult to control devices with output from the EEG process.

It is possible to expand the work here with the various EEG data available to look for other attributes than the available eSense™ values (which are after all just pre-computed from the data itself on the ASIC) and therefore base some biofeedback loop on what is being focused on.

An obvious extension of this project would be the inclusion of VR headset along with the EEG stream provider. Whether the VR headset would interfere either physically or electrically would have to be tested and dependent on the configuration and type involved. Oculus Rift or Google Cardboard type

systems would be appropriate and may be possible to work around.

Along with this, SL is now supporting the Oculus Rift device and viewers are now available to utilise it. This includes the official viewer and others, where it is as simple as pressing a menu button to activate. Bugs do still exist in this initial set-up but with new Rift SDKs are bound to be quickly fixed.

To complete the immersion it would be necessary to combine the VR headset with stereo headphones and EEG reader – this is not such a problem now with weight and size of all devices coming down significantly. Another avenue which may offer intriguing aspects is the High Fidelity virtual world and VR platform which concentrates on interconnection and real time information capture and injection into the virtual world for manipulation of immersed objects [17].

VII. Conclusion

The more immersive virtual technology becomes the easier the techniques employed here will be and a corresponding increase in focus of the user and depth of experience itself. The beginnings of these kind of isolation and immersion mechanisms have already been explored here, beyond the scope light and sound machines currently available.

There are two main conclusions that the work has brought forward:

- The virtual environment can be made responsive to the user's brain state and accompanying brain wave data steam.
- The system can combine merged reality with biofeedback techniques to bring about effects in the user, inducing specific target states.

New headsets such as Oculus Rift and others, when combined with this technology offer ways to interact that were not possible before and biofeedback will play an important role in interactive immersion. This immersion could be toward training individuals to deal with stressful conditions (such as post-traumatic stress disorder [18]) or controlling body reactions, on demand.

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