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IMI Request for Proposals 2010 – 2011

Application Form

**"Call for Research Projects
on IMI Triple I System
(Interaction, Immersion & Innovation)"**

Deadline for Submissions: 20 August 2010

- **By email to: pamsumayao@ntu.edu.sg**

1. GENERAL INFORMATION

Project Title
Seeing, hearing, touching, and controlling your brain waves

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2. RESEARCH DETAILS

2.1 Summary

The Triple I system offers a unique and powerful platform to represent **brain waves** in a tangible fashion; we will use that system to explore the use of computer graphics, sound/music, haptics, and combinations thereof, as a means of representing and analyzing multichannel brain waves, in particular, electroencephalograms (EEG). We will use those representations as real-time feedback to the user; in this way, we can for example create digital paintings or compose music directly through our thoughts. More specifically, we have the following three aims:

Aim 1. We will map EEG signals onto computer graphics, sounds, music, and haptic stimuli; those different representations are generated *simultaneously*, resulting in a virtual reality (VR) that has been sculpted from EEG signals.
We will use sparse time-frequency representations of EEG, which we developed in earlier work [6]; such approach was followed earlier in [4] for EEG sonification. From those representations, one can naturally extract oscillatory events in time-frequency domain; those events can directly and simultaneously be mapped onto:

- **3D scalp maps** (see Fig.1); each event is displayed as a "ripple", similarly as ripples on the water surface of a pond
- **Artistic visual renderings**, in particular, Lindenmayer systems (L-systems; See Fig.5)
- **Music notes** (see Fig.2); the pitch of the notes will represent the electrode location: neighboring electrodes will be represented by similar music notes, whereas remote brain areas are represented by easily differentiable music notes
- **Haptic vibrations**; similarly as for music notes, the frequency of the vibrations will encode the electrode location.

Aim 2. We will use our VR system in an **off-line** fashion, to analyze EEG signals from Alzheimer's disease patients. Our aim is to use our VR system to improve the classification of AD patients vs. control subjects. The underlying hypothesis is that the VR representation of AD EEG is significantly different from EEG of control subjects; for example, the music notes generated from AD EEG may form more complex patterns, since the multi-channel EEG of AD patients is known to be less correlated and more irregular. Likewise, the visualization and haptification of AD EEG may be characterized by more complex structures. By experiencing the three representations of AD EEG *simultaneously* (visualization/sonification/haptification), it may be easier to detect subtle abnormalities in the brain waves of AD patients.

Aim 3. We will develop a **real-time** implementation of the VR system: EEG signals will be recorded in real-time by means of a wireless EEG recording system, and will be represented by the VR system instantaneously. Our objective is to record EEG using a wireless EEG recording system, and to generate scalp maps/L-systems, music, and haptic vibrations from the EEG in real-time. The user will perceive a multi-modal representation of his/her ongoing brain waves, as immediate feedback of his/her mental state. The user can utilize this feedback to change his/her mental state. For example, after sufficient training, it might be possible to create L-systems or to compose music directly from thoughts.

We realize that this project is fairly ambitious, especially given the short duration (one year). On the other hand, many pieces of the puzzle are already in place. We already have developed several Matlab toolboxes in earlier work that will be relevant for this project: a toolbox to extract oscillatory events from EEG, and an EEG sonification toolbox; moreover, Matlab toolboxes have been developed to display scalp maps and L-systems. Therefore, it should be fairly straightforward to develop a first prototype fully in Matlab, that operates offline (not in real-time) on a laptop. The next step will be to design a real-time implementation; the key will be to develop a fast algorithm for extracting the most significant EEG oscillatory events. In parallel, we will implement our algorithms on the Triple I system; we will use the programming language C++, and we will import as much of the existing Matlab scripts as possible. Of course, a large collection of C++ libraries are available as well, for example to generate MIDI files (EEG sonification). From within C++, we will control head models and L-systems designed in 3D Max or Maya.

In summary: we will develop an EEG driven VR system in **Matlab**, which can be run on a **laptop**, and can be used to present demos at conferences and international meetings; that basic Matlab implementation will also serve as prototype for the more sophisticated VR system that we plan to develop on the **Triple I system**.

2.2 Background

The human brain is arguably one of the most complex systems in the universe. Nowadays various technologies exist to record brain waves, e.g., electroencephalograms (EEG) and functional magnetic resonance imaging (fMRI). Those brain imaging tools allow researchers to gain understanding of the complex inner mechanisms of the brain. On the other hand, abnormal brain waves have shown to be associated with particular brain disorders (e.g., Alzheimer's disease and epilepsy). Therefore, the analysis of brain waves plays an important role in clinical diagnosis as well.

Despite the impressive advancements in brain imaging, interpreting brain waves remains an enormous challenge: brain imaging data are often complex and vast; it is often hard to see the forest through the trees.

The Triple I system offers a unique and powerful platform to represent brain waves in a more tangible fashion; it allows us to explore the use of computer graphics, sound and music, haptics, and combinations thereof, as a means of representing and analyzing multichannel brain waves. Such virtual-reality (VR) representation of brain waves has several applications of high potential:

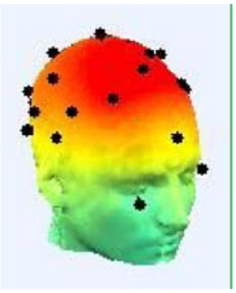

Fig.1 Visualization of brain waves by means of splines (EEG Lab Toolbox [1])

- it may help to detect abnormalities in brain waves, and to diagnose brain disorders
- it may be used for therapeutics, for example, to treat sleeping and attention deficits disorders; it would provide real-time multi-modal feedback to patients about their brain waves, which may allow them to better control their cognitive states
- we can use it to investigate the changes in brain waves during different mental tasks (e.g., working-memory tasks) and conditions (e.g., meditation, fatigue, stress, happiness, fear), which may lead to further insight in the phenomenology of cognition
- it may be used as feedback in brain-computer interfaces (BCI); the latter use brain waves to control devices such as a wheelchair, computer mouse and/or keyboard. BCI systems may provide a communications channel for the motion-disabled. VR-representations of brain waves may help users of BCI systems to focus their thoughts, which in turn may help them to use BCI systems.

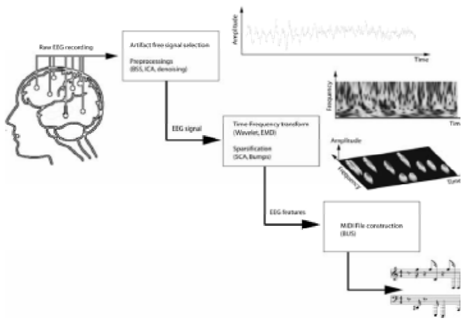

Fig.2 Sonification of EEG signals [4]

We plan to use EEG signals in this project, since these brain signals have excellent temporal resolution; they reliably capture the brain dynamics, which is required for developing meaningful representations of brain processes. Moreover, EEG recording systems are inexpensive, mobile, and wireless.

So far, several studies have investigated the visualization of EEG (see, e.g., [1,2,3], and Fig.1); in [1,2] EEG signals are represented as scalp maps, whereas in [3] the EEG is displayed by means of Lissajou curves. The sonification of EEG signals is much less studied (see [4,5] and Fig.2); haptification of EEG signals is hardly investigated at all. Combinations of those different modalities remain entirely unexplored, yet have strong potential in numerous application areas. Our goal is to explore such multi-modal representations of EEG, thereby leveraging the unique potential of the Triple I system. Obviously, multi-modal representations of EEG may be designed in many different ways, and a seemingly endless variety of combinations can be explored; this project will merely serve as an initial exploration, in which we will experiment with some of the possibilities offered by the Triple I system.

[1] *EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics,* A. Delorme and S. Makeig, Journal of Neuroscience Methods, 134:9-21 (2004).
[2] *EEG Data Driven Animation and Its Application,* Olga Sourina, Alexei Sourin, Vladimir Kulish, MIRAGE 2009, 380-388.
[3] *Biographics Art "I know me": Image Generation Aiming at EEG Control by Biofeedback,* Kosuke Matsunaga and Etsuo Genda, Journal of Physiological Anthropology and Applied Human Science Vol. 24; 139-142 (2005).
[4] *Sparse Bump Sonification: a New Tool for Multichannel EEG Diagnosis of Brain Disorders.* F.Vialatte, T. Musha, and A. Cichocki, Artificial Intelligence in Medicine, 2010 (in press).
[5] *Event-based sonification of EEG rhythms in real time,* Gerold Baier, Thomas Hermann, Ulrich Stephani (2007), Clinical Neurophysiology, vol. 118, no. 6, p. 1377-1386.

2.3 Objectives

We plan to exploit the full potential of the Triple I system for representing brain waves in a more tangible fashion; we will blend computer graphics, sound/music, and haptics, to create a virtual reality (VR) that encodes multichannel brain waves.

Aim 1. We will map EEG signals onto computer graphics, sounds, music, and haptic stimuli; those different representations are generated *simultaneously*, resulting in a virtual reality (VR) that has been sculpted from EEG signals.
We will use sparse time-frequency representations of EEG, which we developed in earlier work [6]; such approach was followed earlier in [4] for EEG sonification. From those representations, one can naturally extract oscillatory events in the time-frequency domain; those events can directly and simultaneously be mapped onto:

- **3D scalp maps** (see Fig.1); each oscillatory event will be displayed as a "ripple", similarly as ripples on the water surface of a pond
- **Artistic visual renderings**, in particular, Lindenmayer systems (L-systems; See Fig.5); the events will be used to define the recursive rules of the L-system
- **Music notes** (see Fig.2); the pitch of the notes will represent the electrode location: neighboring electrodes will be represented by similar music notes, whereas remote brain areas are represented by easily differentiable music notes
- **Haptic vibrations**; similarly as for music notes, the frequency of the vibrations will encode the electrode location.

The EEG oscillatory events are described by five parameters: amplitude, timing, duration, frequency, uncertainty in frequency. Those parameters will be used to generate the different representations: for example, the amplitude of the oscillatory events will be converted into the amplitude of the ripples and vibrations, and the volume of music notes.
The user can interact with the VR system by selecting, for example, EEG channels (and hence brain areas), EEG frequency bands (e.g., theta or beta band), music instruments, etc.

Aim 2. We will use our VR system in an **off-line** fashion, to analyze EEG signals from Alzheimer's disease patients. We have access to several EEG data sets of Alzheimer's (AD) patients and control subjects, and we have analyzed those data sets earlier (see, e.g., [7,8]) (but not in a VR setting). Our aim is to use our VR system to improve the classification of AD patients vs. control subjects. The underlying hypothesis is that the VR representation of AD EEG is significantly different from EEG of control subjects; for example, the music notes generated from AD EEG may form more complex patterns, since the multi-channel EEG of AD patients is known to be less correlated and more irregular; preliminary results along those lines are reported in [4]. Likewise, the visualization and haptification of AD EEG may be characterized by more complex structures. By experiencing the three representations of AD EEG *simultaneously* (visualization/sonification/haptification), it may be easier to detect subtle abnormalities in the brain waves of AD patients. We will ask several subjects to try to distinguish AD EEG from healthy EEG by means of our VR system; first they will be trained with a small subset of EEG data, next they will be tested on the remaining EEG data.

Aim 3. We will develop a **real-time** implementation of the VR system: EEG signals will be recorded in real-time by means of a wireless EEG recording system, and will be represented by the VR system instantaneously. Our objective is to record EEG, and to generate scalp maps/L-systems, music, and haptic vibrations from the EEG in real-time. The user will perceive a multi-modal representation of his/her ongoing brain waves, as immediate feedback of his/her mental state. The user can utilize this feedback to change his/her mental state. For example, after sufficient training, it might be possible to create L-systems or to compose music directly from thoughts.
The EEG signals will be recorded by a wireless system, which is nowadays commercially available (cf. budget plan). The engineering challenge will be to avoid significant delays in the representation; to this end, we will develop an efficient low-complexity implementation of the VR system. For example, we will simplify our procedure [6] for extracting oscillatory events from EEG.

[6] *Bump Time-Frequency Toolbox: a Toolbox for Time-Frequency Oscillatory Bursts Extraction in Electrophysiological Signals,* F. Vialatte, J. Sole-Casals, J. Dauwels, M. Maurice, and A. Cichocki, BMC Neuroscience, 2009, 10:4.

[7] *A Comparative Study of Synchrony Measures for the Early Diagnosis of Alzheimer's Disease Based on EEG,* J. Dauwels, F. Vialatte, and A. Cichocki, NeuroImage, 2010, 49:668-693.

[8] *Quantifying Statistical Interdependence by Message Passing on Graphs PART II: Multi-Dimensional Point Processes,* J. Dauwels, F. Vialatte, T.Weber, T.Musha and A. Cichocki, Neural Computation, 2009, 21(8):2203-2268.

2.4 Detailed Research Plan

First we describe the methodology and plan that we will use to undertake the proposed research and to obtain the stated three Aims. Next we outline how the individual tasks & responsibilities will be divided between project partners.

Aim 1: Translation of EEG signals into computer graphics, sounds, music, and haptic stimuli, resulting in an EEG-generated virtual reality (VR)

1. Visualization of EEG

1.1 EEG scalp maps

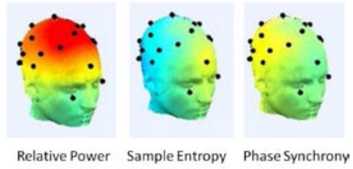

Fig.3. Visualization of brain wave statistics; the head models will be drawn by means of the EEG Lab Toolbox [1] and later on with 3D Max/Maya.

We will visualize the EEG by means of head models (see Fig.1). We will do that in *two distinct ways*: in a first approach, we will generate scalp maps using the entire EEG signal; in a second approach, those maps are generated from the most significant transient oscillations in the EEG ("ripples"), while neglecting the remaining components of the EEG signals (including irrelevant noise). The most significant transient oscillations occur at certain distinct time instances, and therefore, the graphics change only from time to time. In contrast, the first approach displays the EEG as a continuous flow of images, changing smoothly over time.

Continuous-time representation of EEG

We will directly display the EEG signals on a head model (after the usual preprocessing). The EEG values at electrode locations (marked as black dots in Fig.1) are extrapolated to areas between electrodes, e.g., by means of splines [1]. The resulting map of EEG values is displayed on the scalp at each instance of time; since EEG signals vary over time, the scalp maps also vary **continuously** over time. Interestingly, since the 3D location of the electrodes is usually known, the head model can be fitted to those locations, resulting in a fairly accurate representation of the subject's scalp.

The EEG signals are typically noisy, and it is often hard to extract information from them directly, even for highly-experienced neuroscientists and neurologists; to alleviate this issue, it is common practice to compute particular statistics from the EEG signals, for example, the power spectrum, complexity measures (e.g., sample entropy), and measures of statistical dependence (e.g., correlation coefficient, phase synchrony, computed between multiple EEG channels). Those statistics usually vary over time, and we will compute them by means of a sliding window. We will display a variety of (time-varying) EEG statistics using scalp maps, besides the actual EEG signals. Such multi-modal visual representation will help us to grasp the complex nature of EEG signals, and may be used as an EEG monitoring system; it may for example be useful to detect EEG abnormalities, which in turn may help to diagnose certain brain disorders (cf. Aim 2). As an illustration, Fig.4 shows how such display would look like for 3 signal features (relative power, sample entropy, and phase synchrony).

In earlier work [7,8], we have developed *Matlab* code for a large variety of EEG statistics (more than 30 in total). Head models can easily be generated with the EEG Lab *Matlab* Toolbox [1]. As a consequence, it should be fairly straightforward to produce scalp maps of various EEG features in *Matlab*. We will also develop such head models in the 3D software installed on the Triple I system (*3D Max* or *Maya*). We will use C++ as programming language, from which we call *Matlab* scripts and *3D Max/Maya* head models.

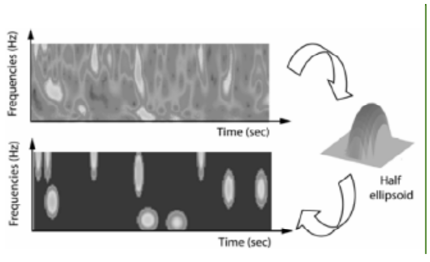

Fig.4.Sparse time-frequency models of EEG [6]

Representation of EEG as sequences of "ripples"

So far, we have described continuous-time representations of EEG. Alternatively, one may extract specific **events** from the EEG, and display those on the head model. As EEG signals may be viewed as a superposition of wave packets, it is natural to define the strongest wave packets as events, corresponding to the most prominent transient oscillations in the EEG signals (see Fig.5; "ripples" in time domain and "bumps" in time-frequency domain). Our earlier work has demonstrated that such sparse time-frequency representations are quite effective low-complexity models of EEG. We have used them to represent various types of EEG responses (e.g., visual evoked potentials), and to analyze EEG of Alzheimer's patients. We have developed a Matlab Toolbox to automatically extract such sparse time-frequency representations [6]: it fits half-ellipsoid basis functions to the peaks in the time-frequency map of the EEG, and consequently transforms an EEG signal in a sequence of time-frequency half-ellipsoid bumps (see Fig.5); each half-ellipsoid bump is described by 5 parameters: its amplitude A, its center in time and frequency (t,f), and width in time and frequency (dt, df). In other words, this sparse time-frequency representation converts EEG signals into sequences of events, where each event is described as a 5-tuple. We will visualize those events on a head model, similarly as in Fig.1: When there are no events, the scalp map is zero everywhere; when an event occurs at time t at a particular electrode, it will be displayed as a transient oscillation ("ripple") with frequency f and duration dt at the location of that electrode; the activity will be extrapolated from electrode locations to points between electrodes, as in the continuous-time scalp maps. In this visualization scheme, the scalp is similar to the water surface of a pond: ripples appear, propagate, and interact with each other.

Again, we will use C++ as programming language, from which we call our *Matlab* scripts for event extraction (cf. Fig.5), and *3D Max/Maya* head models.

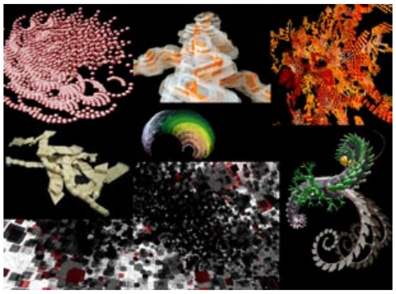

Fig.5.Examples of L-systems

1.2 Artistic visual renderings of EEG

Scalp maps contain much helpful information for neuroscientists and neurologists studying EEG, however, they are not necessarily esthetically appealing. As an alternative, we will explore artistic visual renderings of EEG. We will use EEG signals to create digital paintings, in particular, fractal structures. These organic structures will reflect *changes* in the mental state of the subject over a certain time period. (In contrast, the scalp maps only represent the brain activity at *one* specific time instance.) Specifically, we will develop Lindenmayer systems (L-systems), which are formal grammars that can generate self-similar fractals (see Fig. 4) by recursively applying certain rules. By increasing the recursion level, the form slowly expands and becomes more complex. The ***recursive rules will depend on the EEG signal features***: EEG signals will affect when and how the fractal figures grow. The **color** of fractal sub-structures will also be selected from EEG features. Perhaps the most natural approach is to change the recursive rule whenever a time-frequency event occurs in the EEG (cf. Fig.5); we will choose the new rule depending on the location and/or frequency f of that event. The color of the fractal structures will be selected in a similar fashion. We will experiment with a variety of Lindenmayer systems and production rules. We extract EEG oscillatory events using our *Matlab* Toolbox (see Fig.5.); the latter will be called from within C++, where we generate L-system recursive rules from the extracted events, which in turn will be passed on to *3D Max/Maya* for rendering the actual L-systems.

2. Sonification of EEG

Direct playback of the EEG leads to cacophony; we will develop a sparse and coherent auditory representation instead. We will use the EEG oscillatory events to generate music, similarly as the scalp maps and L-systems. Neighboring brain areas should be represented by similar music notes, whereas remote brain areas should be represented by easily differentiable music notes. According this principle, we convert EEG events (cf. Figs.2 and 4) into music notes as follows:

- Amplitude A of the EEG event will be converted into volume of the music note
- Position of the electrode will be converted into the note pitch, following a pentatonic scale system
- Time instance t and width dt of the event will be converted into onset and duration of the note.

Our collaborator, Dr. Vialatte, has implemented this scheme as a *Matlab* EEG Sonification Toolbox [4]. We will use and extend that toolbox, and combine it with the other system modules (visualization and haptification). Moreover, we will implement this sonification scheme on the Tripe I audiospace system, and we will explore alternative conversions: for example, different electrode locations may be mapped onto different audiospeakers, and the frequency f of the EEG oscillatory events may be converted into note pitch instead.

3. Haptification of EEG

The Triple I system will contain actuators, in particular, vibrators; we will translate EEG oscillatory events into vibrations. The conversion rules will be quite similar as in the sonification scheme (see above).

Aim 2. We will use our VR system in an off-line fashion, to analyze EEG from Alzheimer's disease patients.

As a first step, we will apply our VR system in an offline fashion; in this setting, the algorithms do not need to operate simultaneously and in real-time, which makes it much easier from an engineering perspective. We will apply our system to EEG data of Alzheimer's patients (n=22) and age-matched control subjects (n=38); we have analyzed that data set intensively in the past (see, e.g., [7,8]). The EEG data was recorded in 'rest eyes-closed' condition, by means of 21 electrodes positioned according to the 10-20 international system. The database consists of artifact-free 20s intervals of each EEG recording.

In order to assess whether our VR system helps to distinguish AD patients from control subjects, we will train several subjects (from NTU and elsewhere) during 10 to 30 minutes to classify EEG signals from MCI and Control groups, by means of our VR system. After the training period, the subjects will be exposed to a new set of signals and they will be asked to attribute a value from 0 to 10, reflecting his/her opinion about the status of the patient (0 = clearly AD, 5 = unknown condition, 10 = clearly healthy); this will allows us to quantify the system's ability to represent subtle abnormalities in the EEG of AD patients.

Aim 3. We will develop a real-time implementation of the VR system: EEG signals are recorded in real-time by means of a wireless EEG recording system, and represented by the VR system instantaneously.

Developing real-time representations of EEG is a significant engineering challenge. The representations need to be implemented efficiently, in order to minimize delays. An important step in our VR system is the extraction of oscillatory events from EEG; this process can be substantially simplified by applying multiple bandpass filters in parallel; the filters outputs are integrated over several cycles, and are then thresholded.

We realize that this project is fairly ambitious, especially given the short duration (one year). On the other hand, many pieces of the puzzle are already in place. We already have developed several Matlab toolboxes in earlier work that will be relevant for this project; moreover, Matlab toolboxes for displaying scalp maps and L-systems already exist. Therefore, it should be fairly straightforward to develop a first prototype fully in Matlab, that operates offline (not in real-time) on a laptop. The next step will be to design a real-time implementation; the key will be to develop a fast algorithm for extracting the most significant EEG oscillatory events. In parallel, we will implement our algorithms on the Triple I system; we will use the programming language C++, and we will import as much of the existing Matlab scripts as possible. Of course, a large collection of C++ libraries are available as well, for example to generate MIDI files (EEG sonification). From within C++, we will control head models and L-systems designed in 3D Max or Maya.

Overview of individual tasks & responsibilities

We have assembled a highly motivated and energetic team of researchers, with expertise in signal processing, neuroscience, and digital arts. Our multidisciplinary expertise will be key to our success. In the following, we briefly outline the role of our team members in the project:

1. The PI, Dr. Dauwels, and his research group will be the main driver of this project. Dr. Dauwels has more than 10 years of experience in signal processing at large, and has conducted research on EEG signal processing over the last five years, in intense collaboration with neurologists and neuroscientists. His role will be to supervise and guide students involved in this project, especially regarding the practical implementation issues.

   A Bsc. student at the School of EEE is very excited about this project, and has already committed to work on this project as an EEE UROP, starting in Jan '11; that student is currently carrying out an Industrial Attachment at the Advanced Digital Sciences Center, related to 4D virtual reality. His IA experience is strongly relevant for this project; he will help to develop the EEG visualization methods, in particular, the head model and L-systems in 3D Max/Maya. In addition, several members of the Dauwels Lab are experts in (biomedical) signal processing; they will help to develop various components in the system, i.e., real-time event extraction from EEG [6], integration of EEG sonification algorithm [4], and development of EEG haptification method. In addition, we have requested funding for a research fellow, whose main objective will be to help develop and integrate all system components, and to run tests off-line (with the Alzheimer's EEG data set) and in real-time.
2. The co-PI, Dr. Constable, will help us designing the EEG visualization methods. His expertise in digital painting will be extremely helpful, especially for creating the L-systems.
3. As one of our collaborators, Dr. Vialatte will help us in designing the EEG sonification system. In earlier work, he has developed an EEG sonification toolbox in *Matlab*. Under his guidance, we will use and extend that toolbox, and will integrate it with the EEG visualization and haptification components. Dr. Vialatte has received formal training in neuroscience (PhD level) and computer science (Msc level); he has 5 years of postdoctoral research experience in brain signal processing.
4. Dr. Cichocki has agreed to act as senior advisor for this project; he has been mentoring Drs. Dauwels and Vialatte for 5 years now, and has trained both researchers in brain signal processing during their stints at the RIKEN Brain Science Institute. Dr. Cichocki has exceptional expertise in the area of brain signal processing. For example, his team has recently developed an EEG controlled wheelchair with the fastest response ever reported; this impressive result has widely been reported in the media, including *CNN* and other news channels, and several respected newspapers. Dr. Cichocki's know-how of real-time EEG processing might prove to be quite useful for our project.

Expected Results & Dissemination Plan

Describe in detail future plans and steps to be taken to make demonstrations in the Triple I system. (Maximum 2 pages)

Expected Results

We will develop an EEG driven VR system in **Matlab**, which can be run on a **laptop**, and can be used to present demos at conferences, and domestic/international meetings; the basic Matlab demo will transform EEG onto computer graphics (visualization) and music (sonification); our Matlab implementation will also serve as prototype for the more sophisticated VR system that we will develop on the **Triple I system**, which will generate more refined computer graphics and sounds, in addition to haptic representations of EEG.

Dissemination Plan

- We plan to present our demo at two major international conferences on neural engineering, i.e., ***NIPS*** (Neural Information Processing Systems) and ***ICONIP*** (International Conference on Neural Information Processing). Both conferences have demo sessions, which are meant to enable researchers to highlight scientific advances, systems, and technologies in ways that go beyond conventional oral and poster presentations; such sessions provide a unique forum for demonstrating advanced technologies — both hardware and software — and fostering the direct exchange of knowledge.
- We also plan to submit a journal paper to ***Cognitive Neurodynamics*** based on this work.


Fig.5 LED furniture and interior elements

Future Research

In the longer future, we hope to explore additional **applications** of our VR system, such as the analysis of

- *EEG of epileptic patients*
- *EEG recorded during meditation* (Bhramari Pranayama).

We have access to such EEG data sets and have analyzed them earlier in [9] and [10] respectively (but obviously not in a VR setting). We would use our VR system to:

- explore brain waves before, during, and after epileptic seizures
- investigate how brain waves evolve during meditation.

In both cases, the brain dynamics are quite specific and abnormal, and it would be intriguing to experience the corresponding VR representations. For example, during epileptic seizures, certain brain rhythms emerge and evolve substantially from the onset of a seizure to the ending. Most likely, this will lead to interesting ripple and sound patterns, not only during seizures but perhaps also before the onset of seizures. If the latter is indeed the case, our VR system may be used as an early warning system for seizures.

We would also be quite interested in further exploring **alternative EEG-controlled systems**, especially ones that are appealing from an artistic viewpoint, for example:

- *EEG-controlled living spaces*, where brainwaves are used to color/paint walls, floors, ceilings, furniture, and interior elements. This can be for example realized by means of LEDs (through wireless control) and/or projecting images and movies. Depending on the state of mind, one may project images of a white-sand beach, or a view on the Matterhorn, and change the interior color accordingly.
- *EEG-controlled fashion*, where brainwaves are used to color/paint your clothes. This can be realized, in principle, by means of wireless controlled LEDs (see Fig.6).


Fig.6 LED fashion

At last, we would like to develop EEG-controlled systems with **multiple users**. For example, one can imagine generating L-systems, music scores, or living spaces from the EEG of several users; the latter would form a common VR that would allow users to interact with each other through their thoughts.

[9] *Localization of Seizure Onset Area from Intracranial Non-Seizure EEG by Exploiting Locally Enhanced Synchrony*, J. Dauwels, S. Cash, and E. Eskandar, Proc. 31th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC09), in press.
[10] *EEG paroxysmal gamma waves during Bhramari Pranayama: A yoga breathing technique.* Vialatte FB, Bakardjian H, Prasad R, Cichocki A. Consciousness and Cognition, 2009, 18:977–988.

Ethical, Safety & Regulatory Issues

Please explain in detail how you will deal with ethical, safety or regulatory issues, should your project proposal raise any of these concerns. Any project related to violence or any inappropriate content will not be considered. (Maximum 1 page)

No ethical, safety, or regulatory issues are involved in this project. EEG systems are widely used in clinics and research labs, and have been tested extensively for safety.

We record brain waves and exploit them to control graphics/sound/ haptics, and vice versa. We do NOT stimulate the brain directly by electrical or magnetic stimuli.

3. BUDGET

Budget Allocation

Please describe in detail your proposed budget allocation.

Description	**Amount (SGD)**
Personnel (name, costs)	12-month salary of a research fellow: 65.000 S$ (will be recruited asap)
Travel	Presentation of work at two international conferences: 6.000 S$ (travel expenses + registration + hotel)
Equipment Costs	32-Channel Wireless EEG system: 7.000 S$ (quote from Brilian HighTech Pte Ltd, Singapore)
Others (to specify)	2-week visit of Dr. Francois Vialatte (collaborator at ParisTech) to NTU: 5.000 S$ (travel expenses + hotel)
TOTAL	83.000$S

4. ADDITIONAL DOCUMENTS

Additional Required Documents

4.1 All applicants are required to submit a short CV (maximum of 1 page, A4).

4.2 The Principal Investigator (PI) is required to submit an additional document - 1 short list of the five (5) most important publications highlighting his or her expertise in the proposed field of research.

The following list consists of recent journal papers by Dr. Dauwels related to the analysis of EEG:

J. Dauwels, F. Vialatte, and A. Cichocki,
A Comparative Study of Synchrony Measures for the Early Diagnosis of Alzheimer's Disease Based on EEG, NeuroImage, 2010, 49:668-693.

J. Dauwels, F. Vialatte, T.Weber, and A. Cichocki,
Quantifying Statistical Interdependence by Message Passing on Graphs PART I: One-Dimensional Point Processes, Neural Computation, 2009, 21(8):2152-2202

J. Dauwels, F. Vialatte, T.Weber, T.Musha and A. Cichocki,
Quantifying Statistical Interdependence by Message Passing on Graphs PART II: Multi-Dimensional Point Processes, Neural Computation, 2009, 21(8):2203-2268.

F. Vialatte, M. Maurice, J. Dauwels, and A. Cichocki,
SSVEP useful paradigms in neuroscience, and potential applications in BCI: open questions and challenges, Progress in Neurobiology, 2010, 90:418-438. (invited paper).

F. Vialatte, J. Sole-Casals, J. Dauwels, M. Maurice, and A. Cichocki,
Bump Time-Frequency Toolbox: a Toolbox for Time-Frequency Oscillatory Bursts Extraction in Electrophysiological Signals, BMC Neuroscience, 2009, 10:46.

5. SIGNATURES

We hereby confirm that all the information given in this application and the attachments is correct to the best of our knowledge.

August 20, 2010 Asst. Prof. Justin Dauwels (NTU)
(Date / Name, Designation)

August 20, 2010 Asst. Prof. Martin Constable (NTU)
(Date / Name, Designation)

August 20, 2010 Asst. Prof. Francois Vialatte (ParisTech)
(Date / Name, Designation)

August 20, 2010 Prof. Andrzej Cichocki (RIKEN Brain Science Institute)
(Date / Name, Designation)