Multi Modal Presentation in Virtual Telemedical Environments

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Abstract - Telemedicine can be used to create virtual environments for the collaboration of patient, physicians, and medical staff. Multi modal presentation is increasingly used to improve human-computer interface. In this paper we present a multimodal interactive environment for EEG/MEG data presentation based on Internet technologies and a virtual reality user interface (VRUI). In addition to visualization, VRUI takes advantage of other input/output modalities such as audio. Animation on the 3D models is used to give insight into spatio-temporal patterns of activity. In addition, sonification is applied to emphasize the temporal dimension of the selected visualized scores. Our proposed approach requires only a standard Web browser to run the multi modal viewer which presents 3D EEG topographic maps using a VRML head model which is animated with Java applets.

1. Introduction

Conventionally healthcare services rely on the physical presence and collaboration of the patient, multiple physicians, and skilled medical stuff. Globalization and higher people mobility (business, tourism, etc.), has lead to fragmented care, delivered at scattered locations. However, the healthcare trend is now to provide the latest available information technology to all segments of the community including urban and rural sites. The increased performance of telecommunication infrastructures now facilitates real-time execution of remote applications, establishing a basis for a new medical discipline "telemedicine" [1]. Telemedicine can be used to create virtual environments for collaboration, independently of the participant's physical presence. Therefore, high-quality medical services now become available for distant patients and urgent cases.

The Internet and World Wide Web (WWW) as a global information infrastructure offer a low cost environment for telemedical applications [2]. At the present state of technology, Web based medical applications represent a natural way of creating interactive collaborative environments. Also, Virtual reality (VR) technologies can be used to shift the human-computer interaction paradigm from a graphical user interface (GUI) to a VR-based user interface (VRUI) [3-5]. The main characteristic of a VRUI

is multi-modal presentation. The most frequently used presentation modalities, in addition to visualization, are acoustic and haptic rendering. Immersive environments are particularly appropriate to improve insight into complex biomedical phenomena.
In this paper we present the development of a telemedical environment for multimodal EEG visualization and sonification of brain electrical activity. We propose examination of raw or derived EEG data by using a set of Virtual Medical Devices (VMD). In telemedical applications a VMD has specialized I/O (at patient side), processing (at Web application server), and presentation (at physician side). A VMD allows different views of the same data set. In our example the supported views are either standard waveform electroencephalogram or animated 3D topographic maps of brain electrical activity.

2. Multi-modal presentation

The main issue of multi modal presentation is the design of a VRUI, having in mind the characteristics of human perception. Bernsen [6] proposes the model of human-computer interface with physical, input/output and internal computer representation layers [6]. A two step transformation process is then required for human-computer interaction. For the input it is abstraction and interpretation, and for the output representation and rendering.
Technology and tools for multi modal presentation are commercially available due to the progress of multimedia and VR hardware and software. However, multimedia and VR technology applied simply as a human-computer interface does not guarantee successful presentation.
Conventional applications use uni-modal presentation, minimizing the use of resources, to mediate the information. Simultaneous presentation of the same information in different modalities appears to be a loss of resources. However, our natural perception is based on redundancy. Redundancy in the human-computer interface should be realized using multi-modal presentation. Therefore the main issue in the design of multi-modal presentation is the level of redundancy. A low level of redundancy increases cognitive workload, while a high level of redundancy irritates the user. There is always however an appropriate measure of multi modal redundancy for a given application.
The visualization of large number of data streams leads to visual overloading, and therefore an additional sensory modality, such as acoustic presentation is required to introduce new data streams and increase human-computer communication bandwidth.

3. Sonification

Multi-modal data presentation is a complex problem, due to nature of cognitive information processing. Efficiency of sonification, as an acoustic presentation modality, depends on other presentation modalities. The most important advantages of acoustic data presentation are [7]:

- Faster processing than visual presentation.
- Easier to focus and localize attention in space (appropriate for sound alarms).
- Good temporal resolution (almost an order of magnitude better than visual)

- Additional information channel, releasing visual sense for other tasks
- Possibility to present multiple data streams

Disadvantages of acoustic rendering are:

- Difficult perception of precise quantities and absolute values.
- Limited spatial resolution.
- Some sound parameters are not independent (pitch depends on loudness)
- Interference with other sound sources (like speech).
- Absence of persistence.
- Dependent on individual user perception.

It could be seen that some characteristics of visual and acoustic perception are complementary. Therefore, sonification naturally extends visualization. The system must provide the ability to extract the relevant diagnostic information features. The most important sound characteristics affected by sonification are:

- ***Pitch*** is the subjective perception of frequency. For pure tones it is basic frequency, and for sounds it is determined by the mean of all frequencies weighted by intensity.
- ***Timbre*** is characteristic of instrument generating sounds that distinguishes it from other sounds of the same pitch and volume. The same tone played on different instruments will be perceived differently. It could be used to represent multiple data streams using different instruments.
- ***Loudness*** or subjective volume is proportional to physical sound intensity.
- ***Location*** of sound source may represent information spatially. Simple presentation modality may use *Balance* of stereo sound to convey information.

Early sonification applications have been mostly using the so-called "orchestra paradigm", where every data stream has been assigned its instrument (flute, violin, etc.). Data values are then represented by notes of different pitch. The main advantage of this approach is the possibility to apply standard MIDI support, using a system Application Programming Interface (API). Unfortunately, the proposed approach often leads itself to cacophony of dissonant sounds.

4. Multi modal viewer - mmViewer

One of the most important challenges of contemporary science is how the brain operates. Insight into brain operation is possible using the electrical (EEG) or the magnetic (MEG) component of the brain electrical activity. We implemented an environment for multi-modal presentation of brain electrical activity using 3-D visualization synchronized with data sonification of EEG data. Visualization is based on animated topographic maps projected onto the scalp of a 3-D head model. Our first environment was developed in Visual C++ to test the most important perceptual features [8].

Virtual reality techniques facilitate multiple data stream presentation and navigation through huge data sets. Virtual environments are particularly appropriate to improve insight into complex biomedical phenomena, which are naturally multidimensional.

The Virtual Reality Modeling Language (VRML) is a file format for describing interactive 3D objects and worlds, applicable on the Internet, intranets, and local client systems [9]. VRML is also intended to be a universal interchange format for integrated 3D graphics and multimedia. VRML is capable of representing static and animated dynamic 3D and multimedia objects with hyperlinks to other media such as text, sounds, movies, and images [10]. VRML browsers, as well as authoring tools for the creation of VRML files, are widely available for many different platforms. Therefore we have chosen VRML as widely accepted platform for Internet based information systems. In our system a VRML world is controlled by Java applets. Sonification is implemented as the modulation of natural sound patterns to reflect certain features of processed data, and to create a pleasant acoustic environment. This feature is particularly important for prolonged system use.

Principally, there are two possible multi-modal data presentations. The simplest one is signaling of state transitions or indication of certain states, which is often implemented as sound alarms. The second one is acoustic rendering of a data stream. Additional modes of presentation may be employed either as a redundant mode of presentation emphasizing certain data features or to introduce new data channels. Redundant presentation is intended to create artificial synesthetic perception of the observed process [11]. Artificial synesthesia generates sensory joining in which the real information of one sense is accompanied by a perception in another sense. Multi sensory perception could improve understanding of complex phenomena, by giving other clues or triggering different associations. In addition, an acoustic channel could facilitate new information channels without information overloading.

In distributed medical systems, and telemedical environments, acquisition, archiving and presentation are performed on different physical locations. After acquisition, the original record is archived in a standard format, such as ASTM for EEG [12].

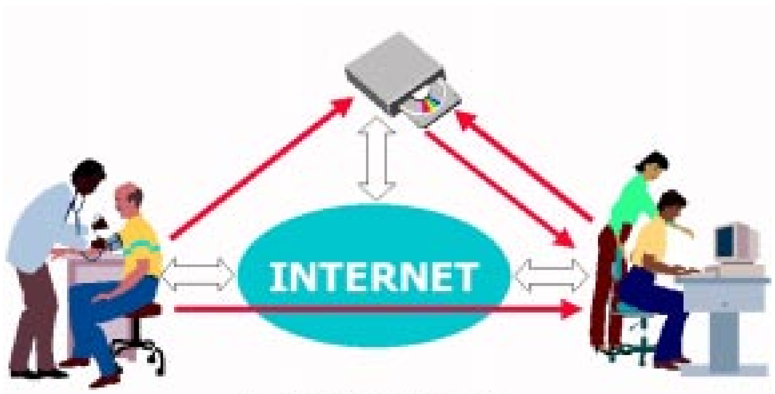

Figure 1. Virtual Medical Devices **VMD**

Physicians can examine the EEG data either on-line, in real-time during recording, or off-line from the archive, and add their findings to the patient medical record, as depicted in figure 1. The presentation of raw or derived data could be performed using tools that allow different views of the data set, as shown in figure 2. We call this set of tools Virtual Medical Devices, or VMD. An example VMD could present a standard electroencephalogram as a waveform plot. We have integrated *mmViewer* as a VMD in a distributed medical information system called *DIMEDAS* [2]. It provides a view of an animated 3D topographic map of selected EEG scores.

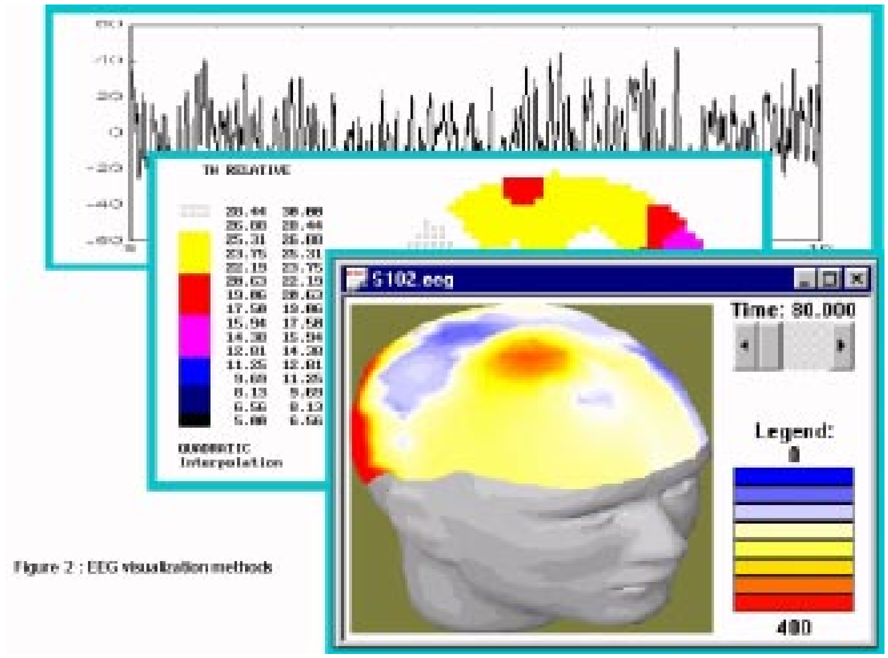

Figure 2 : EEG visualization methods

Topographic maps of different parameters of brain electrical activity have been commonly used in research and clinical practice to represent spatial distribution of activity [13]. The first applications used topographic maps representing the activity on two dimensional scalp projections. They usually represented a static picture from the top view. EEG brain topography is gradually becoming clinical tool. Its main indication is to aid in the determination of presence of brain tumors, other focal disease of the brain (including epilepsy, cerebrovascular disorders and traumas), disturbances of consciousness and vigilance, such as narcolepsy (the abrupt onset of sleep and other sleep disorders grading the stages of anesthesia or evaluation of coma, intraoperative monitoring of brain function in carotid endarterectomy, etc). It is a valuable tool in neuropsychopharmacology and psychiatry. Recent advances in computer graphics and increased processing power provided the means of implementing three-dimensional topographic maps with real time animation, as presented in figure 3. 3-D visualization resolves one of the most important problems in topographic mapping namely the projection of the scalp surface onto the plane. The other problems of topographic mapping are interpolation methods, number and location of electrodes, and score to color mapping.

While in CT and PET images every pixel represents actual data values, brain topographic maps contain observed values only on electrode positions. Consequently, all the other points must be spatially interpolated using known score values calculated on electrode positions. Therefore, a higher number of electrodes produces a more reliable topographic mapping. Electrode setting is usually predefined (like the

International 10-20 standard), although for some experiments custom electrode setting could be used to increase spatial resolution over a certain brain region. Finally, color representation of data values may follow different paradigms like *spectrum* (using colors of the visible spectrum, from blue to red) and *heat* (from black through yellow

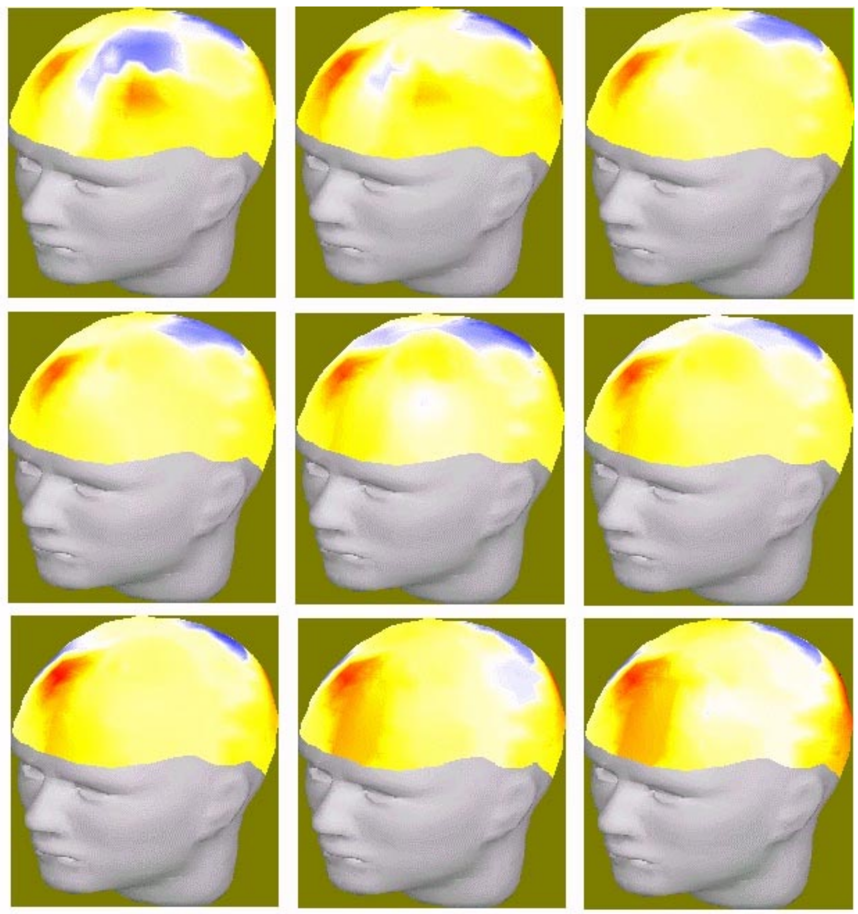

Figure 3 : Sample animated sequence; P(2.5 Hz); T=0.5sec; t=20-24sec

to white) [13]. Isochronous representation of observed processes preserves genuine process dynamics, and facilitates perception of intrinsic spatio-temporal patterns of brain electrical activity.

The multi modal viewer *mmViewer* (Figure. 4) is based on a VRML head model, animated with Java applets. Currently we use a synthetic head model, but we are planning to integrate support for a user-specific head model derived from MRI recording. That model could be archived in the patient medical record, and could be accessed by the web.

Sonification is supported by VRML, using standard VRML nodes *Sound* and *AudioClip*. A Sound pattern is stored in a predefined audio file. A Java applet then modulates the sound according to values in the sonified data stream during animation. We applied sonification to emphasize temporal dimension of selected visualized scores, or present additional parameters. Since the topographic map represents a mass of visual information, we have found very useful to sonify global parameters of brain

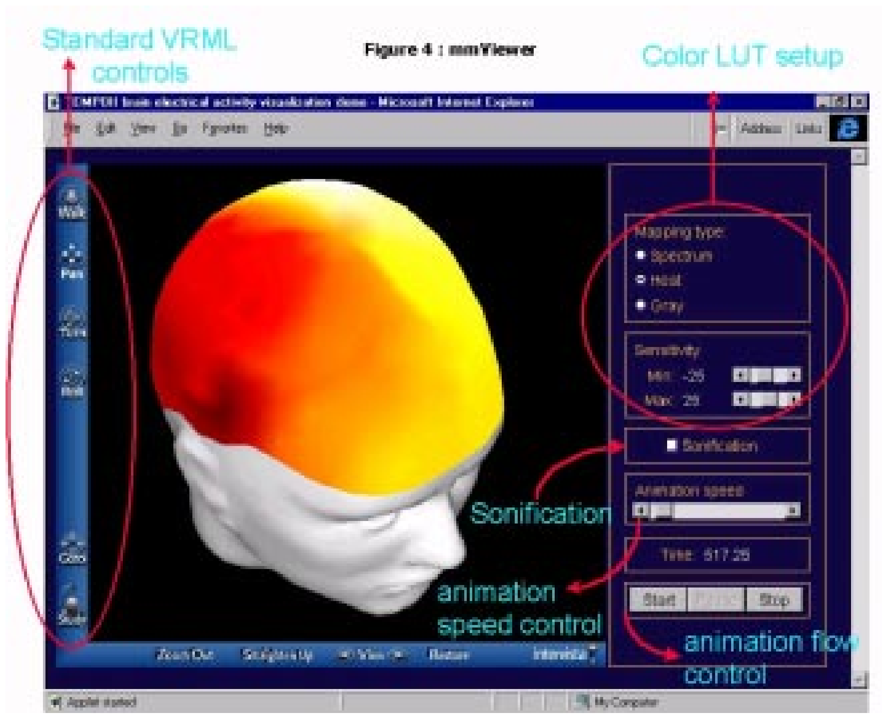

Figure 4 : mmViewer

electrical activity, such as the global index of left/right hemisphere symmetry. The index of symmetry (*IS*) is calculated as:

$$IS = (P_1 - P_2) / (P_1 + P_2)$$

where P_1 and P_2 represent power of symmetrical EEG channels, like O1 and O2 for example. We have sonified this parameter by changing the position of the sound source in the VRML world. Therefore, activation of a hemisphere could be perceived as the movement of the sound source toward that hemisphere.

5. Discussion

The developed system was applied in the analysis of EEG records at the Institute for Mental Health. The performance of the mmViewer on a standard PC/workstation was satisfactory, where the animation speed was often limited by capacity of user perception rather than computer performance.

It was difficult to find the most appropriate multi modal presentation for a given application. We have evaluated different visualization and sonification methods to find out perceptually the most admissible presentation. Moreover, the creation of user-specific templates is highly advisable, as perception of audio-visual patterns is personal.

The selection of scores for multi modal presentation is another delicate issue relying on human perception. The score selected for acoustic rendering may be used either as new information channel (sonification of symmetry in addition to visualization of EEG power) or redundant channel of visualized information. By introducing additional channels one should be careful to avoid information overloading. Redundant multi modal presentation offers the possibility to choose the presentation modality for a given data stream, or to emphasize temporal dimension for a selected stream.

A possible application of sonification could be long-term EEG monitoring in an outpatient clinical practice or intensive care units (ICU). During examination of long EEG records the physician needs to sustain a high level of concentration, sometimes for more than one hour. Monotonous repetition of visual information induces mental fatigue, so that some short or subtle changes in the EEG signal would be probably omitted. Additional acoustic information could help in alerting the observer.

5. Conclusion

Multi modal presentation significantly improves the quality of user interface in virutal telemedical environments. Visualization is usually enriched using sonification and tactile feedback. We presented use of visualization and sonification in the telemedical environment for EEG analysis. We have implemented EEG multi-modal viewer using visualization and sonification in telemedical environment. Since visualization efficiently represents spatial activity distribution, sonification was used either to improve temporal dependency or present new data channels. The proposed multi-modal viewer requires only a standard Web browser and therefore it is applicable both to a stand-alone workstation and distributed Internet based telemedical applications. The lack of general insight into the design of multi-modal presentation, restricts wider acceptance of multi-modal applications. Therefore it is necessary, for a given application, to find the combination of parameters and their presentation modalities to accentuate the changes in a perceptual domain. We are currently investigating the most appropriate presentation paradigm for telemedical EEG analysis.

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