A Multiple-Access Channel Inspired Directional Information Measure for Audio Quality Assessment using EEG

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Abstract

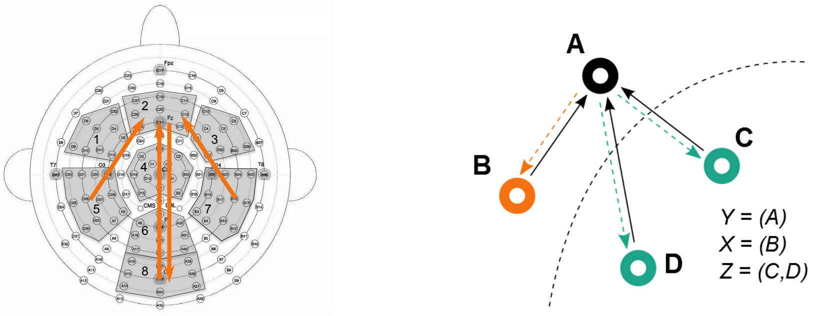
In this work, we provide a novel method using directional information as a measure to evaluate the quality of audio stimulus by directly measuring the EEG response of human test subjects. In particular, we consider the information flow between EEG sensors analogous to a multiple access channel (MAC) with feedback where several senders transmit to only one receiver. We conduct experiments wherein the EEG activity of subjects is recorded as they listen to audio with time-varying audio-quality between two different levels. Different types of directed information measures are then used to measure the causal information flow between EEG sensors, which are grouped into different regions of interest over the cortex. Further, we establish an analytical relationship between the different existing directional measures and derive a new directed information measure based on the cutset bound for the MAC with feedback. The results compare how well these measures are able to successfully distinguish between the perceived audio quality.

I. INTRODUCTION

In the current testing standard for subjective audio quality assessment, subjects assign a single quality-rating score to each test sequence. This methodology suffers from cultural and environmental bias in the testing conditions. By using EEG we can directly record the subjects brain responses which depend only on the change in audio quality. Because of these reasons, there has been a growing interest in using EEG to classify human perception of audio [1], [2] and visual [3]–[5] quality. Our approach here differs from previous studies in that we use directional information to examine the causal relationship between EEG data in response to audio stimulus. Information theory (IT) provides a stochastic framework which is well suited to characterize and model neural response [6], [7], however this is the first time such a model has been applied to study audio quality perception. Our goal here is to investigate the information flow over the cortical network and study the connectivity between different areas of the brain using directional information, to better understand how the brain perceives and responds to changes in audio quality.

II. METHOD

We conduct experiments wherein the EEG activity of subjects was recorded as they listened to audio with time-varying quality. The audio quality varied between two different levels 'high' quality and 'distorted' quality. All stimulus test-sequences were created from three fundamentally different base-sequences sampled at a 'high' quality of 44.1 kHz, with a precision of 16 bits per sample. The 'distorted' quality was obtained by adding one of the following two types of distortion - frequency truncation and scalar quantification. Multiple of such trials were conducted for each subject by choosing all possible combinations of sequences, distortion types, and time-varying patterns. Fig. 1(a) shows the EEG sensors grouped into eight regions of interest (ROI) covering the different cortical regions of the brain. In our work here, we consider the transmission of information over the cortical network to be analogous to a multiple access channel (MAC) with feedback, where several senders transmit information to only one receiver node via a MAC. Additionally, the MAC has a feedback link so the users see the previous outputs of the channel and can use these to choose subsequent channel inputs. Kramer [8] showed that the capacity region for



(a)

(b)

Fig. 1: (a). The EEG electrodes grouped into eight regions of interest (ROI). The grouping scheme efficiently covers the different cortical regions (lobes) of the brain. (b). Information transfer over the ROIs is considered equivalent to a MAC with feedback. In the figure shown above, A is the receiver (output), B is the sender (input), C and D are the side information (inputs) available at the receiver.

a MAC with feedback can be bounded using Massey's directed information (DI) [9] in a form similar to the standard cutset bound for the no-feedback case. For the discrete memoryless case as shown in Fig. 1(b) the bound is given by

$$R \leq \frac{1}{N}\mathrm{DI}(X^N \rightarrow Y^N || Z^N) = \frac{1}{N}\sum_{n=1}^{N} I(X^n; Y_n | Y^{n-1} Z^{n-1}), \tag{1}$$

where X, Y and Z are N length random processes, whose probability distributions satisfy the following,

$$p(x_n, y_n | x^{n-1} y^{n-1} z^{n-1}) = p(x_n | x^{n-1} z^{n-1}) \cdot p(y_n | y^{n-1} z^{n-1}). \tag{2}$$

This serves as the motivation for our new measure wherein we use Kullback-Leibler divergence to calculate the extent of conditional independence of X and Y using (2). We define the new measure as the deviation of the observed data from the product of conditionally independent probability distributions when there is feedback, i.e,

$$\begin{aligned} \mathrm{DI}_{new}(X^N \rightarrow Y^N || Z^N) &= \sum_{n=1}^{N} \mathbb{E}\left[\log \frac{p(x_n, y_n | x^{n-1} y^{n-1} z^{n-1})}{p(y_n | y^{n-1} z^{n-1}) p(x_n | x^{n-1} z^{n-1})}\right] \\ &= \sum_{n=1}^{N} \mathbb{E}\left[\log \frac{p(y_n | x_n y^{n-1} x^{n-1} z^{n-1}) p(x_n | y^{n-1} x^{n-1} z^{n-1})}{p(y_n | y^{n-1} z^{n-1}) p(x_n | x^{n-1} z^{n-1})}\right]. \end{aligned} \tag{3}$$

III. RESULTS

To examine the effectiveness of our approach, the new directional measure was applied to the collected experimental EEG data. Fig. 2 plots DI_{new} (3) calculated between four different ROIs for EEG data extracted from all 10 subjects across all audio trials with different combinations of test sequence and distortion types. The plot shows the directed information calculated separately for both the music qualities for a whole second of EEG trial data. The results indicate a notable difference between the amount of information flow for high and distorted audio. In particular, there appears to be a higher amount of information flow between the cortical regions when the subject is listening to distorted quality audio. This strongly indicates an increase in brain activity when the the subjects are listening to distorted audio, most likely as a result of concentrating harder and paying increased attention to identify the drop in audio quality.

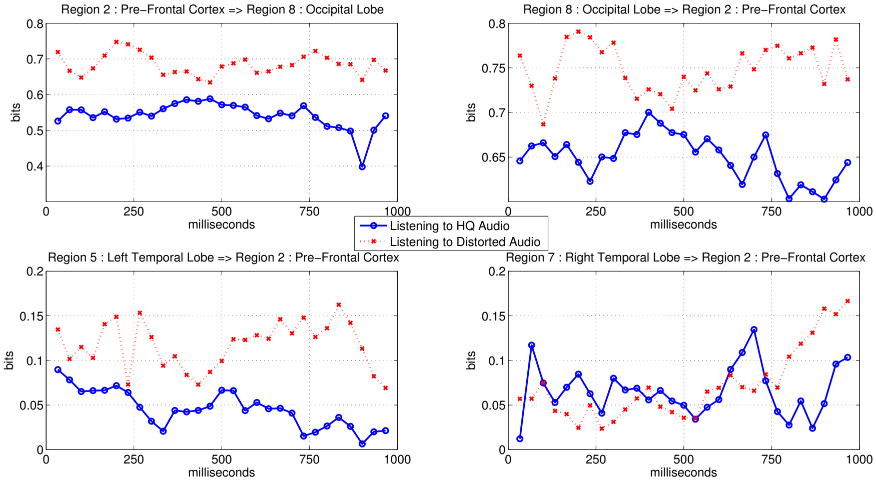


Fig. 2: DI_{new} results showing the difference in the amount of information flow between high and distorted quality audio, calculated between the temporal lobes (auditory cortex), the pre-frontal cortex and the occipital lobe.

REFERENCES

[1] A. K. Porbadnigk, J. Antons, B. Blankertz, M. S. Treder, R. Schleicher, S. Moller, and G. Curio, "Using ERPs for assessing the (sub) conscious perception of noise," in *Proceeding of the 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Buenos Aires, Argentina, 2010, pp. 2690–2693.

[2] C. D. Creusere, J. Kroger, S. R. Siddenki, P. Davis, and J. Hardin, "Assessment of subjective audio quality from EEG brain responses using time-space-frequency analysis," in *Proceedings of the 20th European Signal Processing Conference, 2012*, Bucharest, Hungary, 2012, pp. 2704–2708.

[3] S. Scholler, S. Bosse, M. S. Treder, B. Blankertz, G. Curio, K.-R. Muller, and T. Wiegand, "Toward a direct measure of video quality perception using EEG," *IEEE Transactions on Image Processing*, vol. 21, no. 5, pp. 2619–2629, 2012.

[4] L. Lindemann, S. Wenger, and M. Magnor, "Evaluation of video artifact perception using event-related potentials," in *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization*, Toulouse, France, 2011, pp. 53–58.

[5] M. Mustafa, S. Guthe, and M. Magnor, "Single-trial EEG classification of artifacts in videos," *ACM Transactions on Applied Perception (TAP)*, vol. 9, no. 3, pp. 12:1–12:15, 2012.

[6] F. Rieke, D. Warland, R. De Ruyter van Steveninck, and W. Bialek, *Spikes: Exploring the Neural Code*. The MIT Press, 1999.

[7] A. Borst and F. E. Theunissen, "Information theory and neural coding," *Nature Neuroscience*, vol. 2, no. 11, pp. 947–957, 1999.

[8] G. Kramer, "Causal conditioning, directed information and the multiple-access channel with feedback," in *IEEE International Symposium on Information Theory*, Aug 1998, p. 189.

[9] J. Massey, "Causality, feedback and directed information," in *International Symposium on Information Theory and Its Applications*, 1990, pp. 303–305.