COMBINING EEG FRONTAL ASYMMETRY STUDIES WITH AFFECTIVE ALGORITHMIC COMPOSITION AND EXPRESSIVE PERFORMANCE MODELS

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ABSTRACT

This paper draws together two strands of research in different disciplines: EEG Frontal Asymmetry studies and Affective-based Algorithmic Composition and Performance. There have been numerous studies which support the hypothesis that Frontal EEG asymmetry is an indicator of arousal and valence of emotion. There have also been a number of studies examining which music features are related to which emotional perception, in the generative composition of, and performance of, music. This paper presents a novel system – called the Combined EEG System - which utilises both types of studies. It takes as input raw EEG data, and attempts to output a piano composition and performance which expresses the estimated emotional content of the EEG data. Such a system may be the first step in the development of tools allowing unskilled composers or subjects with problems in emotional expression, to better express themselves through music.

1. INTRODUCTION

Alexithymia is a personality trait which includes (amongst other things) a deficiency in verbally expressing emotions [1]. There are also medical conditions such as autism for which sufferers undergo therapies (including musical) for expression of emotions [2]. The possibility of bypassing the requirement for, verbal expression for such people is obviously attractive. One way individuals with expressive difficulties could express emotion would be through music [3]. Music has often been described as a language of emotions [4]. However such expression usually requires significant musical training. The system described here is a first step towards allowing the musically untrained to express themselves emotionally through music. EEG data is collected from the user, and an attempt is made to estimate their relative affective state. This approximate state is then drives an algorithmic composition and expressive performance system to produce piano music.

2. EEG FRONTAL ASYMMETRY

The standard 10-20 Electrode placement for EEG electrodes [5] is shown in Figure 1. Two of these, “F3” and “F4”, can be used to give a measure of what is known as EEG Frontal Asymmetry – the difference in a certain frequency band of power between the left hand and right hand side of the front of the brain (i.e. between F4 and F3).

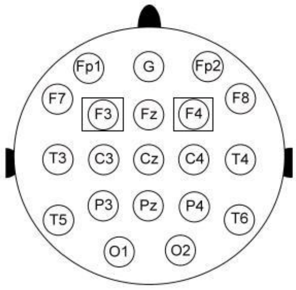

Figure 1. Standard Electrode Placings

[6] proposed that there was a link between asymmetry of frontal alpha activation and the valence of a subject’s emotional state. “Valence” refers to the positivity or negativity of an emotion – e.g. a high valence emotion is joy or contentment, a low valence one is sadness or anger. The idea of valence is used in the 2D emotional representation [7]. In this model, emotions are plotted on a graph with the first dimension being how positive or negative the emotion is (Valence), and the second dimension being how strong the emotion is (Arousal). For example: Happy – Positive Arousal, Positive Valence and Fear – Positive Arousal, Negative Valence.

[8] found that frontal brain EEG distinguishes Valence and Arousal of music-related emotions. Schmidt and Trainor give results for happy, sad, angry and fearful. Their results focused on a frequency band called the “Alpha” band. Their result indicated for example:

- Happy - increased left frontal alpha relative to right frontal alpha indicates increased valence
- Fearful - increased over-all frontal alpha indicates an increased arousal

3. AFFECTIVE ALGORITHMIC EXPRESSIVE PERFORMANCE AND COMPOSITION

How do humans make their performances sound so different to the so-called “perfect” but robotic performance a computer would give? Two of the most common performance actions found in Western “classical” music are changing the Tempo and the Loudness of the piece as it is played. These should not be confused with the tempo or loudness changes marked in the score, like accelerando or mezzo-forte, but to

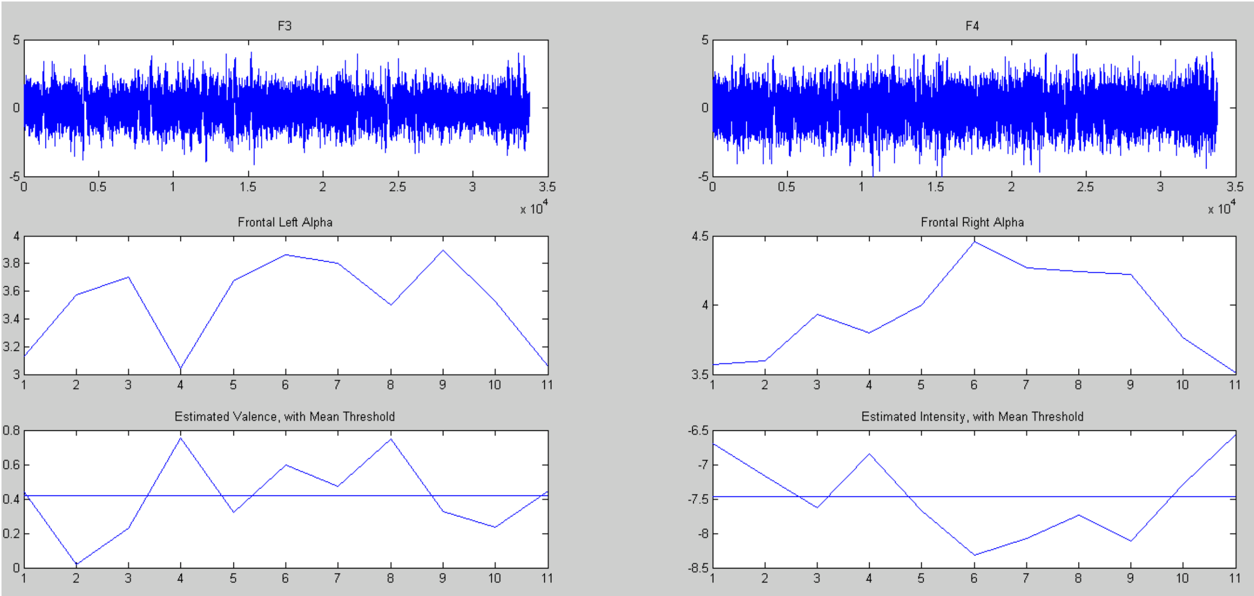

Figure 2. Standard Electrode Placings

additional tempo and loudness changes not marked in the score. For example, a common expressive performance strategy is for the performer to slow down as they approach the end of the piece [9]. Another factor influencing expressive performance actions is Performance Context. Performers may wish to express a certain mood or emotion (e.g. sadness, happiness) through a piece of music. Performers have been shown to change the tempo and dynamics of a piece when asked to express an emotion as they play it [10].

Computer Systems for Expressive Music Performance (CSEMPS) are systems designed to add such expression to non-expressive computer performances [10]. One of the most influential CSEMPs – and the one utilised in this paper – is Director Musices. As well as applying humanisation, Director Musices is able to implement emotional expression [13], drawing on work by Gabrielsson & Juslin [10]. As a result parameters were estimated for 6 rules which mould the emotional expression of a piece.

There has been research into affective expression through algorithmic composition, e.g. [13] as well. It was found that the addition of the microfeature humanisation rules improved the accuracy of the emotional expression (as opposed to solely using macrofeature "recomposition" rules).

4. COMBINING EEG ASYMMETRY WITH AFFECTIVE ALGORITHMIC COMPOSITION/PERFORMANCE

The recorded EEG data for F3 and F4 is processed and used to estimate the emotional state of the EEG data - i.e. the valence and arousal levels - using equations (1) and (2) below. These equations are based on simple models used in previous EEG Asymmetry research. In EEG measurements greater power implies lower activity:

$$Valence = \ln(\text{frontal alpha power(left)}) - \ln(\text{frontal alpha power(right)}) \quad (1)$$

$$Arousal = -(\ln(\text{frontal alpha power(right)}) + \ln(\text{frontal alpha power(left)})) \quad (2)$$

To give an example of affective state estimation, consider the following. EEG data was recorded with a subject listening to a sequence of excerpts of Ambient and Hard Rock music, interspersed with silence. The music was presented for approximately 15 seconds each time. The result EEG analysis (which has been edited for recording artifacts) is shown in Figure 2.

5. ALGORITHMIC COMPOSITION AND PERFORMANCE

The Composition/Performance process of the system is illustrated graphically in Figure 3.The initial function in the composition process is the generation of the piece structure. The user defines the top level structure, such as "aba", "abca", or "aabb". This structure is used to generate two lower levels: theme and phrase structures in a recursive self-similar way. The phrases that make up the structure (i.e. the actual notes) are supplied by the user. Examples of ways of generating phrases include: phrases supplied by a composer, phrases generated using a cut-up algorithm applied to a provided whole melody, and phrases generated by a separate algorithm. Phrases should be monophonic and contain some rhythmic as well as pitch content.

During the next stage of the composition, an expressive performance element is applied: (a) to humanise the output and make it sound less computer-based, (b) to express the affective state estimated from the EEG more effectively. However the Director

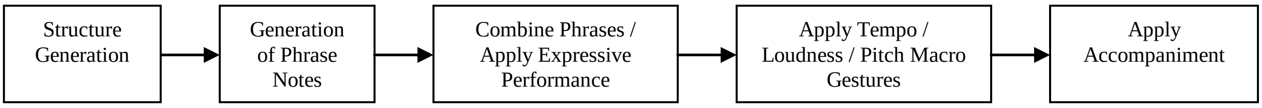

Figure 3. Composition/Performance Process

Musices Emotion model is not continuous in valence and arousal – i.e. there is no simple mapping from continuous valence and arousal indices on to the parameters of the DM emotional expression performance model. The Combined EEG System generates continuous estimates of valence and arousal. So for the emotional performance system a similar methodology to [13] is utilised and four DM emotions are selected as representing the 4 quadrants of valence/arousal. Specifically happiness, sadness, anger, and tenderness are selected.

The system makes larger - "compositional" - adjustments to key, pitch and tempo to generate emotional expression similar to those found in [13]. One way this is done is to change pitches based on emotion. Livingstone proposes that more positive and active emotions (happiness) have higher average pitches than more negative and passive emotions (e.g. sadness). Based on this a series of linear equation rules were implemented for pitch. Livingstone suggests the use of Major keys for Happiness, and Minor keys for Tenderness and Sadness. However, unlike Livingstone minor keys are not used for "Anger" in the Combined EEG System. The reason for this is that as long as the phrases provided to the system are atonal, a keyless state appears to be closer to communicating "Anger" than a Minor key. This approach is not utilized in Livingstone's CMERS, since it recomposes pieces rather than building new pieces. The key changes in the Combined EEG System are applied in a non-continuous way using the "Representative Emotion" quadrant already described. The speed, pitch and loudness are changed continuously based on valence and arousal values based on [13] using linear equations.

Also included in the process is a simple tool for accompaniment. The accompaniment is based on piano-heuristics developed by the authors of this paper.

6. AN EXAMPLE USAGE

New EEG data was recorded with a subject (the first author) listening to the same sequence of excerpts of Ambient and Hard Rock music, interspersed with silence. Two compositions were generated from these settings. The initial phrases were up to 6 seconds long and were generated using a simple alleatoric composition algorithm [14]. In terms of testing the system, it is outside of the scope of this paper to re-examine the effectiveness of using EEG asymmetry measurements to estimate affectivity. Only the simple common results of previous research were used in the design, rather than attempting to develop new EEG hypotheses. The main new factors that have been incorporated into the process are the algorithmic composition elements (which are not identical to [13]), a novel accompaniment algorithm, and combined process itself. All pieces were given the same emotional profile. Two of the pieces were randomly chosen and played to 3 independent listeners. The listeners were asked to mark up the time where they perceived changes in valence and changes in arousal. The results of the listening experiments are displayed in Table 1, showing how accurately each subject identified the 5 affective changes inserted into the 2 tracks.

The first thing to note is that there was only 1 run where a subject detected five states – this was subject 3 on track 2. All other runs except that one detected extra states (1 extra state was detected in 3 cases, and 2 extra states in one case). This means that the subjects tended to perceive more changes in valence and arousal than there actually are. This is not particularly surprising, given that the source material used to generate the material – the phrases - was not controlled for affective content itself. As source phrases are pasted together to make the track, the pitch and timings of the initial phrasing may influence the affective perception.

	Track 1		**Track 2**	
	Valence	*Arousal*	*Valence*	*Arousal*
Subject 1	4/5	3/5	4/5	4/5
Subject 2	4/5	3/5	4/5	3/5
Subject 3	3/5	4/5	5/5	4/5

Table 1. Results broken down into Valence and Arousal

Another element to observe is that the subjects' perceptions of affective state sometimes matched solely in arousal, sometimes solely in valence, and sometimes in both. It is useful to evaluate separately the system's relative abilities in expressing these two dimensions. Note that a subject is marked as having detected one of the 5 affective states if during the time period the system is trying to express that state, the subject actually detects that particular valence or arousal state. They may detect other states as well in that time, but they will still be marked as having detected the correct state. As long as there are not a large number of incorrectly additional states identified in that time period, this will be considered a sufficient demonstration of concept. That is because both EEG and music are very approximate input and output communication modes, rather than precise symbolic specifications [15][16]. Hence the best that could be hoped for was approximate accuracy in time in the music expression.

Based on Table 1 there is an average 80% communication rate for Valence and a 70% communication rate for Arousal, though timings vary from the programmed change times. This observation needs to be considered in light of the fact that during the 6 tests (a total of 30 states) there were 5 extra states detected which were not intended by the system; and also 1 state was entirely missed. It also needs to be observed that the breaking down into Valence and Arousal dimensions is not an infallible method – they are a simplified model of emotion. Hence any results based on that breaking down are subject to the same limitations. Also these tests do not validate the EEG-to-emotion methodology, but purely support the feasibility of the use of the composition/performance part to communicate that emotion.

The aim of the Combined EEG System is to indicate *changes* in valence and arousal in a user through EEG and music. So it would to aim to increase the valence communicated in the music, if the valence increased in the user's EEG pattern. It is not an attempt to literally detect if the user is happy, sad, etc.

7. CONCLUSIONS

This paper has drawn together two strands of research in different disciplines: EEG Frontal Asymmetry studies and Affective-based Algorithmic Composition and Generative Performance. In this paper a novel system which utilises both sets of studies has been presented – it takes as input raw EEG data, and attempts to output a piano composition and performance which expresses changes in estimated emotional content of the EEG data. Initial testing results were given that suggest that the system is worth developing and performing extended testing on. There are a number of possible areas for future work for the system: the algorithmic composition toolbox could be improved; the accompaniment algorithm is very simple, and is not affectively manipulated; and finally, and most importantly, more work needs to be done on verifying and improving the EEG-to-emotion detection model.

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