# EEG Analysis to Decode Perceptual Ability of Human Subjects

*Synopsis submitted by*

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The word "Perception" is synonymous with the act of perceiving. However, perception has a wiser meaning in cognitive neuroscience. It refers to the biological process of acquiring information from the external world using our sense organs and also understanding the message carried therein. Perception, in general, is a vast and unexplored research arena, and there exists ample scope of research opportunity for its underlying importance.

The current research on perception revolves around the structural and functional aspects of different brain modules and their interconnections. Apparently, a perceptual process, such as olfaction, is localized as it involves only the pre-frontal and temporal lobes of the brain. The localized activity involved in a perceptual process offers primitive interpretation carried by the percept. For instance, the pre-frontal lobe processes the olfactory stimuli to recognize the stimuli. However, if the aroma perceived is associated with one or more additional events, such as association of a person with a perfume, the brain employs multiple lobes to understand the true meaning (here, the presence of the person carrying the aroma) of the stimulus. Thus, perception in a bigger sense includes higher level cognition, triggered with external stimuli.

The thesis aims at understanding the biological basis of perception by analyzing the brain signals acquired from the scalp of the subjects during excitation of the brain with external stimuli. Electroencephalography (EEG) offers the temporal activity of the human brain during stimuli acquisition and understanding. This inspires researchers to understand the biological processes involved in perception from the time-domain, frequency-domain and time-frequency correlated characteristics of the acquired brain signals. Although there are several brain-signaling and imaging techniques to uncover the mystery behind the underlying perceptual processes, EEG is preferred to its competitors for its spontaneous (having good temporal resolution) response, portability and non-invasive characteristics. This justifies our choice of EEG for the present research.

Although there is an immense scope of research on understanding the biological basis of perception using EEG signal analysis, we have restricted our research into three main heads. The restriction is apparent due to limited time duration of the Ph.D. research and non-availability of the suitable subjects in a non-hospital environment. The first problem is concerned with subjective perceptual-ability detection and ranking when stimulated with aromatic substance. The problem has importance in diverse domains of applications, including selection of tea-tasters from a list of candidates, testing perceptual-ability of the early Alzheimer's patients and determining the degree of Alzheimer from the estimation of their perceptual-ability etc. The second problem deals with a very interesting subject concerning cognitive-failure detection in driving. The importance of the second problem is apparent for its application in safety-critical driving. The third problem is targeted to detect the tactile perceptual-ability of psychologically retarded people and/or patients suffering from Schizophrenia and other brain-related diseases.

The thesis includes five chapters. Chapter 1 provides a thorough review of the EEG-based research undertaken on perception. It begins with a definition of perception and perceptual-ability and also explores different brain signaling/ imaging techniques including EEG, Positron Emission Tomography (PET), functional Magnetic Resonance Imaging (fMRI) and functional Near-Infrared Spectroscopy (fNIRs). The later part of the chapter covers well-known brain signals and their association with different cognitive processes. Special emphasis is given to single and multi-modal BCI problems. The Later part of the chapter deals with standard techniques of problem-solving, such as pre-processing and artifact removal, feature extraction, feature selection and classification. Next the chapter provides a discussion on the current research directions associated with the problems undertaken in the thesis. The scope of the thesis is also appended at the end of the chapter.

Chapter 2, 3 and 4 are original contributions of the thesis. Here, the candidate provides three distinct problems in perception engineering and offers solutions to these problems by extending the traditional techniques of pattern recognition. Although the problems have their own diversity, the commonality of the problems lies in utilizing and extending computational intelligence techniques adopted for pattern recognition. The other common aspect of the problems undertaken and the approaches adopted include that the analysis of all the problems are performed in real time. Naturally, time required for execution of the algorithms here play a vital role for their amenability in real world systems.

Chapter 2 addresses one interesting problem on olfactory perceptual-ability detection of human subjects, where the motivation is to detect the individual perceptual-ability of the subject and rank them in descending order. These subjective ranks offer the user the relative merits in decoding aromatic substance. Traditional supervised learning techniques, such as support vector machines (SVMs), back-propagation learning etc. could have been used to solve the problem. However, the existing techniques are appropriate for small class size and thus unsuitable for the present application, requiring large (equals to 10) class-size, and that too in real time. To alleviate the present problem, we employed a Hopfield-like recurrent neural classifier, the stability of which is ensured at multiple optima of a selected Lyapunov energy surface. In the classification of aromatic stimuli from the pre-frontal EEG response of a subject, we first need to map the EEG-features of the individual olfactory stimulus to one of the local optima in the Lyapunov energy function of the energy-surface. This mapping is done automatically by the selection of the weight matrix of the Hopfield-like dynamics with an aim to minimize the selected Lyapunov energy function for the dynamics. In the present context, we develop an alternative formulation, where a multi-modal high dimensional Rastrigin function is used as the Lyapunov energy surface. Thus for the selected energy surface, we construct a Hopfield-like dynamics, which essentially ensures mapping of the olfactory stimuli to the local optima.

Once the weight matrix of the Hopfield dynamics is ready, we can use it as a classifier. This is done in a tricky way. Suppose we measure the feature vector of an unknown olfactory stimulus. The feature vector is mapped onto the Lypunov energy surface. We initialize the Hopfield-like dynamics at the mapped location of the energy surface, and solve the differential equation until it converges at one of the nearest optima. Since each optimum is earmarked with one smell class, we declare the smell class associated with the optimum as the target class. Experiments undertaken confirm that the proposed technique of classifying olfactory perceptual-ability of subjects outperforms traditional techniques by a good margin.

Existing literature in driving primarily focuses attention to physiological aspects of the drivers and the failures related to gestural/postural aspects in driving. However, online detection of cognitive failures from the brain signals is yet a virgin arena of research in traffic engineering. The thesis introduced an interesting approach to design a set-up for on-line cognitive failure detection of the drivers from three fundamental aspects. These are i) visual alertness failure detection, ii) motor planning failure detection and iii) motor-execution failure detection.

In Chapter 3, the candidate proposes a novel scheme of cognitive failure detection in driving using brain signals. Although there exist different types of cognitive inability responsible for driving failures, we here adopt three possible cognitive failures, called visual attention failures (VAF), motor planning failures (MPF) and motor execution failures (MEF). VAF refers to cognitive failures due to lack of visual perception. Primarily, in driving context, visual attention failure takes place when the driver is not visually attentive. In case the driver is visually attentive, we test any possible failure in motor planning by the subject. The failures involved in motor planning include possible mistakes in executing braking, acceleration and/or steering control.

Occasionally it is noticed that the driver planned his motor activities correctly and timely but failed in executing the planned task. This is generally due to muscle fatigue and/or poor health condition and/or stray situations on part of the driver. The third test adopted is detection of cognitive failures in motor execution.

Testing of cognitive failures has been accomplished by acquiring the EEG signals from three distinct brain lobes. To detect VAF, we acquire EEG signal from the pre-frontal, frontal and occipital lobes. MPF detection requires examining brain signals from the parietal lobe and motor cortex, while MEF is detected from the EEG acquired from the motor cortex region only. These electrical signals are pre-processed using Independent Component Analysis (ICA) to eliminate artifacts, and then passed through band-pass filters of specific frequency bands for individual cognitive tasks. For instance, the EEG acquired for VAF detection is filtered in the alpha band (8-13 Hz), while the EEG signal acquired in motor planning and execution is filtered in the mu-beta bands (8-30 Hz). Next the filtered signals are processed to extract certain signal features. For the VAF detection problem, we extract adaptive autoregressive (AAR) parameters and for MPF and MEF detection we extract power spectral density (PSD) and discrete wavelet transform (DWT). The feature dimension, usually being moderately high (of dimension = 78) for MPF and MEF, we reduce it by a novel evolutionary feature selection algorithm. The algorithm autonomously generates a set of fixed dimensional features from the total list of features, and examines the best set of features for which the intra-class distance is minimized and inter-class distance is maximized. This is done by measuring fitness of the individual trial solutions, where the fitness measure indicates the degree of maximization of inter-class distance and minimization of intra-class distance jointly. The evolutionary process generates expectedly improved trial solutions over the program iterations, and thus when the terminating condition is reached, the best-fit candidate solution represents the highest degree of satisfaction of both the said criteria.

The main research component of the work lies in designing a suitable classifier, capable of classifying VAF into two classes: visually attentive or non-attentive, MPF into four classes: braking failure, acceleration failure, steering control failure and no failure, and MEF into three classes: braking, acceleration and steering control execution failures. Each of the above three classes is again classified into two sub-classes: brake pressed or not pressed and the like. The classifiers are supplied with extracted features for the respective cognitive failure, and the classifier response is the detected class. Apparently, any traditional supervised learning classifiers could serve the purpose. However, because of parallel brain activations and stochastic noise associated with eye blinking and other muscle movements, the features are often found noisy. The creeping of noise in the features makes the traditional classifiers unsuitable for the MPF detection. For the VAF and MEF, however, support vector machine (SVM) classifier has acceptable performance.

The fundamental problem in the present research thus is to design a classifier worthwhile for classification of motor planning classes in presence of stochastic noise in the EEG features. Fuzzy sets, in general, and type-2 fuzzy sets in particular, have inherent characteristics to take precise decisions in presence of noisy measurements. While classical (type-1) fuzzy sets can capture the noise due to the randomness of the measurement, type-2 fuzzy sets can capture intra- and inter-personal level uncertainty that might appear in a decision-making system because of the randomness in the assignment of memberships within and across experimental subjects respectively. Here, we propose two distinct models of type-2 fuzzy classification, one realized with interval type-2 fuzzy sets (IT2FS) and the other with general type-2 fuzzy sets (GT2FS). The IT2FS-induced classifier determines the average degree of membership of a data point (by taking the average of the upper and lower membership functions at the given measurement point) in a given class, and declares the class with the highest membership as the class for the given data point. The GT2FS-induced classification employs secondary grades as additional input to tune the primary membership function in each class to determine the degree of membership of a data point in a given class. The class with the highest secondary grade induced primary membership for a given data point is declared as the winning class. A thorough comparison of the IT2FS- and GT2FS-induced classifiers is provided in the chapter to examine the relative merits of GT2FS-based classifier over its counterpart.

The fourth chapter is concerned with touch perception, where the motivation is to classify the touch nourishment received by psychological patients from different nurses in a hospital environment. The objective is to select the right nurse by individual patient for their highest degree of pleasure during the phase of mental treatment. Touch perception is primarily active in the somato-sensory cortex. The nearest electrodes available are frontal and parietal electrodes and the motor cortex region. EEG signals acquired from the above electrodes of the patients are first pre-processed and filtered from artifacts. The processed signals are then fed to a classifier to recognize the pleasure levels received by the patients.

The classifier design is given primary consideration in the present work. We adopted radial basis function (RBF induced back-propagation neural networks to classify the pleasure level of the patients. The RBF-neural network selects specific touch nourishments, such as soft touch, rubbing, messaging and embracing. Next, for a given touch nourishment we select a back-propagation neural network to classify the individual touch nourishment into three classes: pleasant, acceptable and unpleasant. Experiment undertaken reveals that the proposed neural architecture outperforms its competitors with respect to classification accuracy. To test statistical validation of the proposed classifier performance, McNemar's test is employed. The proposed scheme has successfully been realized to select appropriate nurses by Schizophrenic patients based on the degree of qualitative touch perceived by them across nurses.

The thesis ends with a concluding chapter dealing with the self-review of the works undertaken in chapters 2, 3 and 4 and also possible future research directions.

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