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Classification of intelligence quotient via brainwave sub-band power ratio features and artificial neural network

A.H. Jahidin*, M.S.A. Megat Ali, M.N. Taib, N.Md. Tahir, I.M. Yassin, S. Lias

Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

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ABSTRACT

This paper elaborates on the novel intelligence assessment method using the brainwave sub-band power ratio features. The study focuses only on the left hemisphere brainwave in its relaxed state. Distinct intelligence quotient groups have been established earlier from the score of the Raven Progressive Matrices. Sub-band power ratios are calculated from energy spectral density of theta, alpha and beta frequency bands. Synthetic data have been generated to increase dataset from 50 to 120. The features are used as input to the artificial neural network. Subsequently, the brain behaviour model has been developed using an artificial neural network that is trained with optimized learning rate, momentum constant and hidden nodes. Findings indicate that the distinct intelligence quotient groups can be classified from the brainwave sub-band power ratios with 100% training and 88.89% testing accuracies.

1. Introduction

Cognitive performance, described in terms of intelligence is characterized by information processing capabilities of the brain [1]. The ability differs between individuals [2] and is influenced by time [3] and experiential learning [4]. The underlying model of intelligence has been established through the neural efficiency theory [5]. The theory states that brighter individuals are less mentally active than people with average intellectual ability [6]. This is achieved through focused use of resting brain and disuse of irrelevant brain area for good task performance [7]. The phenomenon is reflected by lower glucose metabolism in brighter individuals [8]. Although receiving criticism [9], the theory has been reinforced through a variety of studies employing different neurophysiological measurement methods and a broad range of cognitive task demands [10].

Mental processing is performed by the frontal cortex. It performs executive functions of the brain which include the ability to regulate emotion, anticipate and plan for the future, make rational decisions and shape behaviour towards attainment of motivational goals. The functionality of the frontal cortex can further be divided into the left and right hemispheres where different regions exhibits different cognitive ability. The left hemisphere is involved in sequential and logic processes. The right hemisphere however, is specialized for social interactions and emotional capabilities [11].

Psychometric tests have been established to gauge an individual's ability on various aspects of intelligence. This would include the intelligence quotient (IQ), working memory capacity, non-reasoning tasks, problem solving, learning

* *Corresponding author*. Tel.: +60 12 6194590.
E-mail address: aisyah23@gmail.com (A.H. Jahidin).
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[12], mental rotation [13], and verbal reasoning [14]. Majority of studies relating intelligence with brain activity have utilized problem solving and non-reasoning tasks to stimulate intense mental activity. Brain activities are measured using various measurement modalities such as the functional magnetic resonance imaging (fMRI), positron emission tomography (PET) [5], and the electroencephalogram (EEG) [15]. All the findings consistently support the neural efficiency hypothesis [5]. In non-reasoning tasks, results show that although no reasoning was required, information processing differs between individuals of varying intelligence [12].

The EEG is a recording of electrical fluctuations of the brain, commonly known as brain waves. The signal exhibits an irregular and continuous oscillating pattern with frequencies varying from 0.5 to 100 Hz. The frequency characteristics heavily rely on the intensity of mental activity in the brain. Distinct patterns can be observed under varying conditions through the delta, theta, alpha and beta waves [16].

Delta wave with very low frequency range 0.4–4 Hz prevails in deep sleep and is commonly a precursor in comatose condition. The theta waves, however, are present in light sleep and are often associated with emotions and creativity. The signal exhibits a frequency range 4–8 Hz [17]. In relaxed state, the rhythmic alpha wave with frequency range 8–12 Hz is prevalent. In the event of intense mental activity however, the alpha wave would be replaced by the beta wave that exhibit higher frequency of between 12 and 30 Hz [16].

In the past, characterization of brainwave features has taken numerous approaches. In relation with mental performance, several studies have utilized band power to observe the effects on the alpha and beta waves. It has been observed that during mental stimulation, a less intelligent individual would demonstrate higher beta with lower alpha power as compared to the brighter ones [7,13,15,18–22]. These have been confirmed through the power ratio method that looks into the theta, alpha and beta sub-band inter-relationships [23–25]. In addition, similar studies have also directed to brain-related disorders such as the attention-deficit/hyperactivity disorder (ADHD) [26–28], chronic fatigue syndrome [29], and Alzheimer's disease [30].

The artificial neural network (ANN) is a machine learning method that is inspired by the working of biological neurons in the brain. The technique enables supervised learning through back-propagation update procedure on the weights of neuron connections to minimize the output error [31–33]. ANN has established itself in a variety of biomedical applications, which include disease recognition [34–36], chromosome detection [37], physiological analysis and modelling [38,39]. Previous works on modelling of brain behaviour using EEG have looked into characterization of epilepsy [40] and vigilance level [38]. In addition, application of ANN on EEG has also been implemented for brain–computer interface [41].

Conventionally, intelligence assessments are only conducted using established psychometric tests such as the Wechsler Intelligence Scale and Raven Progressive Matrices (RPM). Recent studies in variety of neurophysiological, many researches were done to correlate intelligence with brain activity [6,13,42–45]. Evaluation of IQ based on scientific technique however, is new. Although there are attempts to estimate IQ using ANN, the study focuses on estimating IQ from different psychometric tools instead of EEG brainwaves [46]. There is still a gap in knowledge connecting complete systematic approach on IQ measurement via intelligent technique and EEG brainwaves. Hence the paper presents an intelligent approach to evaluate IQ from resting EEG. The IQ-brain behaviour model is developed using sub-band power ratio features from the left brain hemisphere in closed eyes condition and ANN. The use of resting EEG in closed eyes condition to classify IQ was based on a previous study which revealed that brain activity pertaining to intelligence can be distinguished in its resting state (tonic), and in the absence of cognitive demanding task [47–49]. It was also discovered that pre-task resting conditions reflected state differences within non-clinical young adults [50].

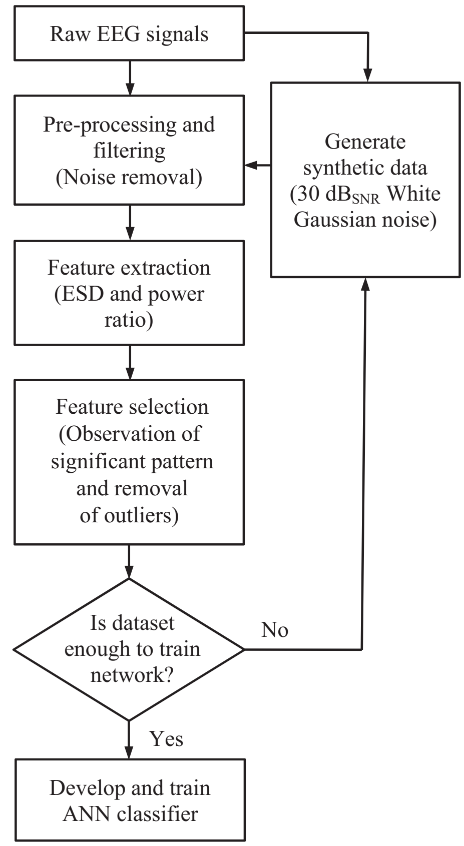

Fig. 1 – Flow chart of research work.

2. Methods

This section explains extensively on the overall processes that were implemented for this research work. It consist of EEG data collection, pre-processing, feature extraction, feature selection, generation of synthetic data and finally development of brain behaviour model using ANN as illustrated in Fig. 1.

2.1. *EEG data collection and IQ test*

Approval from the University Ethics Committee was obtained and all volunteers were required to complete the consent form