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Low-complexity hardware design methodology for reliable and automated removal of ocular and muscular artifact from EEG

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ABSTRACT

Background and objective: EEG is a non-invasive tool for neuro-developmental disorder diagnosis and treatment. However, EEG signal is mixed with other biological signals including Ocular and Muscular artifacts making it difficult to extract the diagnostic features. Therefore, the contaminated EEG channels are often discarded by the medical practitioners which may result in less accurate diagnosis. Many existing methods require reference electrodes, which will create discomfort to the patient/children and cause hindrance to the diagnosis of the neuro-developmental disorder and Brain Computer Interface in the pervasive environment. Therefore, it would be ideal if these artifacts can be removed real time on the hardware platform in an automated fashion and then the denoised EEG can be used for online diagnosis in a pervasive personalized healthcare environment without the need of any reference electrode.
Methods: In this paper we propose a reliable, robust and automated methodology to solve the aforementioned problem. The proposed methodology is based on the Haar function based Wavelet decompositions with simple threshold based wavelet domain denoising and artifacts removal schemes. Subsequently hardware implementation results are also presented. 100 EEG data from Physionet, Klinik für Epileptologie, Universität Bonn, Germany, Caltech EEG databases and 7 EEG data from 3 subjects from University of Southampton, UK have been studied and nine exhaustive case studies comprising of real and simulated data have been formulated and tested. The proposed methodology is prototyped and validated using FPGA platform.
Results: Like existing literature, the performance of the proposed methodology is also measured in terms of correlation, regression and R-square statistics and the respective values lie above 80%, 79% and 65% with the gain in hardware complexity of 64.28% and improvement in hardware delay of 53.58% compared to state-of-the art approaches. Hardware design based on the proposed methodology consumes 75 micro-Watt power.
Conclusions: The automated methodology proposed in this paper, unlike the state of the art methods, can remove blink and muscular artifacts real time without the need of any extra electrode. Its reliability and robustness is also established after exhaustive simulation study and analysis on both simulated and real data. We believe the proposed methodology would be useful in next generation personalized pervasive healthcare for Brain Computer Interface and neuro-developmental disorder diagnosis and treatment.

1. Introduction

Neuro-developmental disorders (NDD) including Attention Deficit Hyperactivity Disorder (ADHD), Schizophrenia, Down syndrome, Autism Spectrum Disorder (ASD), intellectual retardation, learning disablement are impairments in the evolution of the brain or the central nervous system which manifest early in the development, often during infancy or before child enters into the socio-academic education. While the symptoms and behavior of NDD including language and speech learning, motor synchronization, behavior, retention, imagination under-development, communication [1] differ from individual to individual, some children with such disabilities in the childhood develop permanent damages. For

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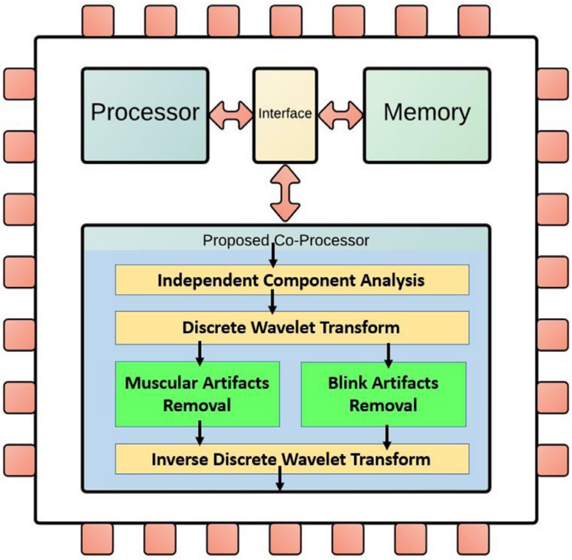

Fig. 1. Block Diagram along with the flow-chart of the proposed system.

example, children with ASD show impairment in social interaction, deficit in communication and motor coordination, repetitive or stereotyped behavior, lack of cognitive skills, language loss, and atypical visual perception [2–6].

To diagnose NDD for ASD, Autism Diagnostic Observation Schedule (ADOS) and Autism Diagnostic Interview-Revised (ADI-R) are used comprising of a series structured tasks and interviews respectively involving the interactions among patient, examiner and parents. The examiner identifies the patient's response to the tasks and suggests a proper treatment procedure [7]. However, such procedures involve a constant observation on the children, significant amount of parenting, treatment time and huge long-term expenses. The recent Neuroimaging techniques that discovered an overgrowth of the cortical white matter and abnormal pattern in frontal and temporal lobe during prenatal and postnatal period of brain evolution generally require a sedation and radioactive dye [8]. Both of the above-mentioned procedure requires high quality medical facilities for intensive care in home environment.

On the other hand EEG- electrical recording of the brain systematic activity along the scalp, measured by the voltage fluctuations resulting from the ionic current which flows within the neuron [8–10], is cost-effective and non-invasive tool for the exploration of different brain regions for cognitive and other event-related activities of a subject [8,10]. The diagnostic feature extracted from the EEG signals can reveal the brain functionality in the area of particular task and can be used as a biomarker to classify between the NDD and healthy control. In fact, EEG has also been arguably the most widely used mechanism for acquiring brain computer interface (BCI) signals from the brain for the control of computers or other devices via the modulation of neurological activity in the participant's' brain without the need of any activation of the efferent nervous system [11]. However in daily life, since EEG signal is mixed with other biological signals of non-interest [10,12], including blink and muscle artifacts, it is difficult to extract the diagnostic features. Therefore, Medical Practitioners during offline visual observation, tend to discard the EEG channels containing these artifacts [2] which results in less accurate diagnosis [13]. Similarly, in case of online automated diagnosis using EEG in tele-health framework under internet of things, these artifacts may cause wrong diagnosis triggering false alarm and causing panic. Recently, there is an attempt to propose an online and automated EEG artifacts removal scheme in [11,14,15] targeting BCI where, although the processing is done online, the acquisition of the data is still done off-line which deviates from the need of our envisaged goal of having a pervasive personalized healthcare monitoring system.

Pseudo Code 1. DWT Computation.

Notations: F = sampling frequency, T = total time for which EEG is Observed, C_a = DWT Approximate Coefficient, C_d = DWT Detailed Coefficient.

1. DWT Level 1

$$C_{aj}^{1} = \frac{(f_i + f_{i+1})}{\sqrt{2}} \quad C_{dj}^{1} = \frac{(f_i - f_{i+1})}{\sqrt{2}}$$

j = number of coefficients in Level1 1, 2… $n/2$

2. DWT Level z

$$C_{ak}^{z} = \frac{C_{aj}^{z-1} + C_{aj+1}^{z-1}}{\sqrt{2}} \quad C_{dk}^{2} = \frac{C_{aj}^{z-1} - C_{aj+1}^{z-1}}{\sqrt{2}}$$

k = number of coefficients in Level2 1, 2 …. $n/2^z$

z = number of DWT level decomposition

Therefore, a robust methodology which would remove the effect of these artifacts as well as retrieve EEG amidst the presence of these artifacts would be extremely helpful for BCI and also for enhanced diagnosis of NDD in real-time online personalized home care environment. But since, the frequency spectrum of blink and muscular artifact overlaps with the normal EEG signal, it poses a commendable challenge in achieving the target of retrieving artifact free EEG in real-time automated fashion on hardware platform. To tackle this challenge the researchers use Independent Component Analysis (ICA) Blind source Separation and wavelet based time frequency algorithm to remove the ocular artifacts [10,16–23] and muscular artifacts [13,15,20,22,24] from the EEG [41–43]. Although these methods are non-invasive, most of these methods (except [11,12,14,15]) require external ocular electrodes near the eyes, which will cause discomfort thereby making it unsuitable for the personalized remote health care. Furthermore, such arrangements make the patients/children conscious about the presence of these extra electrodes, which causes hindrance to the appropriate diagnosis of the NDD. In [12] the need of these ocular electrodes have been eradicated however, this recent method does the processing of the data acquired offline [12].

Motivated by the fore-mentioned challenges, in this paper, we propose:

- a reliable, robust and automated low complexity hardware design methodology to remove blink and muscular artifacts real time without the need of any extra electrode;
- a mechanism for online EEG based NDD diagnosis in a pervasive personalized healthcare environment;
- a methodology with comparable accuracy when compared with state of the art approaches and that can be implemented in a low complexity fashion on a chip-set to ensure the battery backup, that drives electronics, sustains for longer time than the state of the art approaches and
- an FPGA implementation along with the hardware complexity analysis with power consumption of only 75 micro-Watt.

The paper is organized as follows, Section 1 describes materials and methods, Section 2 proposes the methodology, Section 3 presents the results, necessary comparisons and relevant discussions and finally Section 4 concludes the paper.

2. Materials and methods

2.1. Prerequisites

Fig. 1 depicts the block diagram of the system based on the proposed methodology. A 21 and 64 channel EEG signal mixed with