Instrumental Activities of Daily Living (IADL) Evaluation System Based on EEG Signal Feature Analysis

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***Abstract*—This work proposes an IADL evaluation system using LDA algorithm based on EEG signal, which explores the correlation between the subjective IADL assessment and the objective EEG signals measurement. Five features are extracted from the single channel EEG device including average amplitude, power ratio, spectral central, spectral edge frequency 25% and 50%. These features are represented as an indicator of participant's IADL and are classified as IADL scales using LDA algorithm. For system evaluation, thirty elderly participants (70 ~ 96 years old) are classified into three groups by IADL score: high (disability-free, 16~24 points), medium (mild disability, 8 ~ 15 points) and low (severe disability, 0 ~ 7 points). These IADL groups distribute uniformly to conduct following IADL scenarios; 1. Ability to use telephone, 2.Ability to handle finances, and 3.Chat with people (that is not included in IADL scenario). The experiment result shows that the proposed EEG features and evaluation system can achieve 90% average accuracy rate verified by Leave-One-Out cross validation (LOOCV).**

***Keywords*—IADL, Electrocardiography, EEG, Linear discriminate analysis (LDA), power ratio, spectral center, spectral edge frequency**

I. INTRODUCTION

In the development of medical care technology, an accurate and efficient analysis of physiological signal for health monitor has drawn much attention such as Electrocardiography (ECG), Electroencephalogram (EEG) and Electromyography (EMG). These signals are used to record and detect the user's physiological state, and then analyzed for the clinical care in real-time.

Healthcare organization appraises Instrumental Activities of Daily Living (IADL) scale scores of a cognitive decline patient through interviews with family members and patient. However, the Instrumental Activities of Daily Living Assistive Assessment (IADL-AA) is utilized to subjectively assess the personal physiological state, which is not considered the objective measurement by physiological measurement.

Fabrizio *et al*. [1] examined the brainwave correlation between the Alzheimer's disease (AD) and the Mild Cognitive Impairment (MCI), and found that the AD patients whose brainwave in Delta and Theta wave band of energy are relatively stronger, and Alpha and Beta ones are relatively weaker than the MCI patients. Moretti *et al.*[2] assessed the MCI and AD patients in the hippocampal atrophy and estimated the difference between two bands of Alpha (8-12 Hz) and Alpha 2 (7-13 Hz) brainwave. Therefore, the correlation between the brainwave signal and the IADL score is rarely investigated. Lawton *et al* [3] proposed IADL-AA, which is a used scale to assess independent living skill. IADL scales have been tested further for their usefulness in a variety of types of institutions and other facilities serving community-resident older people.

This work focuses on exploring the relationship between the EEG signal and IADL assessments. Five features are used for extracting the EEG signals in the proposed IADL evaluation system, including average amplitude, power ratio, spectral centroid, spectral edge frequency 25% and 50%. The proposed system not only measures the IADL score of the patient by the chatting with a personnel that can replace the traditional methods, but also assists doctor objectively to judge the IADL scale of the patient more preciseness. The experimental result shows that the proposed system can achieve 90% of average accuracy for IADL objective measurement.

In the following, Section II describes the proposed evaluation system including system framework, feature extraction of EEG and LDA-based EEG analysis for IADL score scale. Section III gives experimental setting of the evaluation system, and Section IV presents the experimental results of the evaluation system. Conclusion is presented in section V.

II. IADL EVALUATION SYSTEM BASED ON EEG SIGNAL FEATURE ANALYSIS

Figure 1 shows the framework of the proposed system. EEG signal is measured using signal channel EEG sensor with 512Hz sampling rate. Five features are extracted to represent the characteristic features in time domain and frequency domain. EEG signal is transformed into frequency band by Discrete Fourier transform, and the brainwave bands (Alpha, Beta, Delta and Theta) are selected between 2-100Hz in frequency band. LDA-based classifier is used to identify the meaning of the characteristic curves for test subjects.

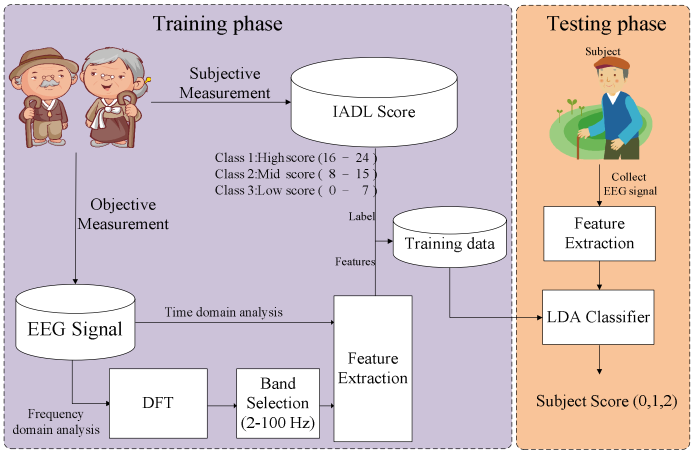


Fig. 1. Framework of the proposed system.

A. *Feature Extraction of EEG*

EEG is the recording of electrical activity which is the voltage fluctuations resulting from ionic current flows within the neurons of the brain [4]. In clinical contexts, EEG is the recording of the brain's spontaneous electrical activity from signal electrical placed from multiple electrodes placed on the scalp over a short time. Diagnostic applications generally focus on the spectral content of EEG, therefore, the type of neural oscillations that can be observed in EEG signal.

For feature extraction, the average amplitude of the EEG is time domain-based feature which is measured by 180 seconds and assessed by peak-to-peak analysis as (1).

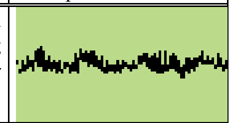
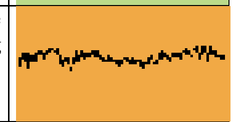
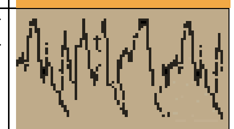
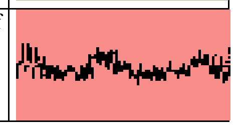
$$Average\ Amplitute = \frac{\sum_{n=1}^{N} |x(n)|}{N} \tag{1}$$

where $x(n)$ is EEG signal, and N is the number of sampling signal. Regarding to the feature in frequency domain, $x(\cdot)$ is transformed to spectrum $f(\cdot)$ by Discrete Fourier Transform (DFT) [5] as (2).

$$f(n) = \sum_{n=0}^{N-1} x(n) W_N^{nk} = \sum_{n=0}^{N-1} x(n) e^{-j2\pi k/N} \tag{2}$$

Then the frequency in terms of brainwave, $f(n)$, which is classified into four types of bands, namely α-band (8~12Hz), β-band (12~40 Hz), δ-band (2~4 Hz) and θ-band (4~8 Hz), the function of the various brainwaves is shown in Table I.

TABLE I
THE FUNCTION OF THE VARIOUS BRAINWAVES

Types of bands	Example
Alpha: when we are in a state of physical and mental relaxation, although aware of what is happening around us, its frequency are around 8 to 12 pulses per second.	
Beta: emitted when we are consciously alert, or we feel agitated, tense, afraid, with frequencies ranging from 12 to 40 pulses per second in the Hertz scale.	
Delta: when there is unconsciousness, deep sleep or catalepsy, emitting between 0.1 and 4 cycles per second.	
Theta: more or less 4 to 8 pulses, it is a state of somnolence with reduced consciousness.	

Four various feature types of these wavebands are utilized for EEG Power Ratio (EEGPR) [6],which is defined as the power ratio of slow to fast EEG activities, for averaged spectrum, absolute and relative power in four standard wave band as shown in (3).

$$EEGPR = \frac{(\delta - \text{band power} + \theta - \text{band power})}{(\alpha - \text{band power} + \beta\text{ - band power})} \tag{3}$$

Next feature is the spectrum centroid which is calculated from the center of mass in (4), if the spectrum centroid is in a high quality, indicates that the frequency energy is concentrative distribution in the higher frequency band [7].

$$Spectral\ Centroid = \frac{\sum_{n=0}^{N-1} f(n)x(n)}{\sum_{n=0}^{N-1} x(n)} \tag{4}$$

To further indicate brain activities, the SEF is utilized to determine threshold values, sensitivity and specificity of the EEG. Both the SEF25 and the SEF50 are indicated that the frequency below 25 percent and 50 percent of the total power spectrum [2 – 100 Hz].

B. *LDA Classifier*

Linear Discriminant Analysis (LDA)[8] is an analysis used in statistics to find a linear combination of features, we suppose that each of C classes, the LDA consider maximizing the flowing in (5):

$$J(w) = \frac{w^T S_b w}{w^T S_w w} \tag{5}$$

Where S_b is the between classes scatter matrix and S_w is the within classes scatter, the definitions of scatter matter are:

$$S_b = \sum_c (u_c - u)(u_c - u)^T \quad (5)$$

$$S_w = \sum_c \sum_{i \in c} (x_i - u_c)(x_i - u_c)^T \quad (6)$$

where u is the overall mean of the data, and u_i is the mean of the classes. For instance, the classes may be partitioned, and Fisher Linear Discriminant Analysis is used to classify each partition. A common example of this is "one against the rest" where the points from one class are put in one group, and everything else in the other, and then LDA applied. This will result in C classifiers, whose results are combined. Another common method is pairwise classification, where a new classifier is created for each pair of classes (giving C(C − 1)/2 classifiers in total), with the individual classifiers combined to produce a final classification.

C. *LDA-based IADL Scale Correlation with EEG*

The proposed LDA-based scoring measurement aims at creating an automatic IADL measuring system by inspecting the correlation between the subjective IADL and the objective EEG signals. Thirty elders are classified into three groups by the subjective IADL score scale including high score (disability free), medium score (mild disability) and low score groups (severe disability). Then three groups are mapped to the objective features extracted from EEG signals through the same participants. The steps of LDA-based IADL scale correlation with EEG schema are described as follows:

1). Collect the subjective IADL score from thirty elderly participants and classify into three scores groups.

2). Collect the objective signals from EEG through the same participants and map to three groups.

3). The extracted EEG feature set of each participant is attributed to three groups of IADL scores correspondingly.

4). LDA classifier for IADL is acquired and test by using the Leave-one-out cross validation.

5). When we collect new EEG data, the system used LDA decision coefficient and LDA classify database to calculate the IADL subproject score and map to three groups.

III. Experimental Setting

In data acquisition, totally eight evaluation items in the IADL-AA [3] are assessing, including 1) Ability to use telephone, 2) Shopping, 3) Food Preparation, 4) Housekeeping, 5) Laundry, 6) Mode of Transportation, 7) Responsibility for own medications and 8) Ability to Handle Finances. In order to decrease the risk in the experiments, two effortless terms, that is, the ability to use telephone and the ability to handle finances, within the IADL-AA are selected in the experiments.

On the other hand, two experiments are considered in our work including eyes opening and chatting status, which are frequently used in EEG experiment. Above four terms are measured to collect the brainwave signals by the single channel EEG device. In IADL-AA, the collected data from the thirty elderly participants over sixty are collected through assessing the IADL, and the scored data are classified into three types of levels, i.e. the high, medium and low scored groups. In EEG measurement, the sampling rate of single channel EEG is 512 Hz.

TABLE II.
Experimental participants

	Low	Mid	High	Total
Number of Participants	9	9	12	30
Gender (M/F)	3/6	3/6	9/3	15/15
Average Age	84	76	78	79

In sample category stage, thirty samples are separated into three parts: 9 low-score (severe disability) samples, 9 mid-scores (mild disability) samples, and 12 high-scores (disability free) samples, shown in Table II.

Five minutes duration of brainwave signal is collected in a sample, then omitted the prior sixty second of the sample, then using the subsequent 180 seconds of duration for the feature extraction and use the LDA classifier to classification, total five extracted features are collected from one participant.

IV. Experimental Result

In the experiment, the collected data from the thirty elderly participants, four items are used in experiment including 1) Use Telephone, 2) Handle Finances, 3) Opening eyes and 4) Chatting and five features are used for EEG signals and then mapped to the IADL three scaled groups (high, medium, low). Leave-One-Out Cross Validation (LOOCV) is used to verify the proposed system, by using one participant's data for outside test, and leaves n-1 data for the training.

The accuracy of the proposed system can reach to 90% is shown in Table III. The Experimental result indicated that the IADL items have close relationship with EEG signal. And our proposed system can measure the IADL-scores using EEG signal in the chatting status.

TABLE III
Experimental Result

IADL evaluation items	Participants	Correct	Accuracy
Use Telephone	30	27	90%
Handle Finances	30	26	86.67 %
Normal	30	27	90 %
Chatting	30	28	93.33 %
Average Accuracy			90%

V. Conclusion

In this paper, an automated IADL scale assessment system is proposed. Five features are utilized as EEG signal features including 1) average amplitude, 2) power ratio, 3) spectral centroid, 4) SEF25 and 5) SEF50. LDA classifier is used for IADL scale classification. In system evaluation, thirty brain wave data of elders are verified through LOOCV to know that use the LDA classifier, experimental results demonstrate the proposed system can effectively classify the IADL groups. The IADL average recognition rate can reach 90%, and the proposed system can evaluate the IADL scale just using the brain wave data that is collected in chat scenario.

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