EMG Signal Based Human Stress Level Classification Using Wavelet Packet Transform

Article *in* Communications in Computer and Information Science · September 2013

1 author:

Murugappan M
Kuwait College of Science and Technology

EMG Signal Based Human Stress Level Classification Using Wavelet Packet Transform

P. Karthikeyan, M. Murugappan, and Sazali Yaacob

School of Mechatronics Engineering, Universiti Malaysia Perlis (UniMAP)
Ulau Pauh, 02600, Arau, Perlis, Malaysia
karthi_209170@yahoo.com

Abstract. Recent days, Electromyogram (EMG) signal acquired from muscles can be useful to measure the human stress levels. The aim of this present work to investigate the relationship between the changes in human stress levels to muscular tensions through Electromyography (EMG) in a stimulated stress-inducement environment. The stroop colour word test protocol is used to induce the stress and EMG signal is acquired from left trapezius muscle of 10 female subjects using three surface electrodes. The acquired signals were preprocessed through wavelet denoising method and statistical features were extracted using Wavelet Packet Transform (WPT). EMG signals are decomposed to four levels using db5 mother wavelet function. Frequency band information's of third and fourth levels are considered for descriptive analysis. Totally, seven statistical features were computed and analyzed to find the appropriate frequency band and feature for stress level assessment. A simple non-linear classifier (K Nearest Neighbor (KNN)) is used for classifying the stress levels. Statistical features derived from the frequency range of (0-31.5) Hz gives a maximum average classification accuracy of 90.70% on distinguishing the stress levels in minimum feature.

Keywords: Stress, EMG, stroop colour word test, wavelet packet transform, KNN classifier.

1 Introduction

Stress is one of the major factors that affect the life style of most adults in developed and developing countries. Especially in US, 90% diseases and disorders is related to stress [1]. Stress levels can be computed using a scientific stress level measurement tool and to relive the stress by suggesting suitable relaxation methods. In this view, several researches have investigated different methods to compute stress level using biochemical or physiological signals [2, 3]. Physiological signal based approach is more futuristic than biochemical methods due to its unobtrusive and simple measurement. However, physiological signal based approach has several issues in data acquisition and processing. Solving of these issues will greatly enhance the results of stress assessment experiment. Researchers have investigated different types of physiological signals such as Electrocardiogram (ECG), EMG, Galvanic Skin

S.G. Ponnambalam et al. (Eds.): IRAM 2012, CCIS 330, pp. 236–243, 2012.

Response (GSR), Electroencephalogram (EEG), and Skin Temperature (ST) for stress assessment [4-10]. Compared to other physiological signals, ECG discussed in several stress assessment studies [11]. We have already carried out a series of analysis on ECG signals to assess the stress level of the subjects using different stress inducement protocol [7]. This present study is focusing on investigating the EMG signal from trapezius muscle for stress assessment. Human muscles consist of voluntary and involuntary contractions. Voluntary muscle is to move the body that could be easily controllable by brain through Autonomic Nervous System (ANS). Similarly, involuntary muscles are not easily controllable through brain such as cardiac muscles, blood vessels, muscles in digestive and reproductive systems. This involuntary muscle also generates action potential during the stress state. This action potential is reflected on facial and trapezius muscles [12]. Researchers have found that, trapezius muscle is an ideal location to identify involuntary muscles activity of cardiac regions. Previously, Healey and Lundeberg et al. studied the characteristic changes on EMG signal in trapezius locations and confirmed the measurable changes on the signal stress [6, 13]. However, Very few literatures only reported on EMG signals based stress assessment. Indeed, the discussion on the effects of different frequency bands, more feasible signal processing methodology for non-linear signals for assessing stress level changes is also limited. This present study is concentrated to solve the above issues using suitable signal processing methodology to identify the optimum frequency bands and features after applying the involved in preprocessing, feature extraction, and classification.

2 Methods and Materials

2.1 Research Methodology

This present work mainly aim to investigate the characteristics of EMG signals on assessing the stress level changes of the subjects. Fig 1 shows the research methodology of this work. Initially, stroop colour word test based stressor was used to induce the stress and EMG signals are simultaneously acquired from left trapezius muscle, which is an indicator of soft muscle activity. The acquired EMG signals are preprocessed using wavelet denoising method [14] and wavelet packet transform (WPT) is used for extracting the statistical features. These features were normalized and finally these statistical features are mapped into four different stress levels namely; relax, low, medium and high using a simple non-linear (KNN) classifier. Three EMG electrodes made up of Ag/Ag-Cl are placed on the trapezius muscle of the subjects and signal was obtained with sampling frequency range of 500 Hz. Acquired EMG signals are preprocessed using DWT based denoising method for removing the noises (power line, external interferences) and artifacts (respiration). The complete stress inducement protocol and data acquisition information is explained our previous work [7].

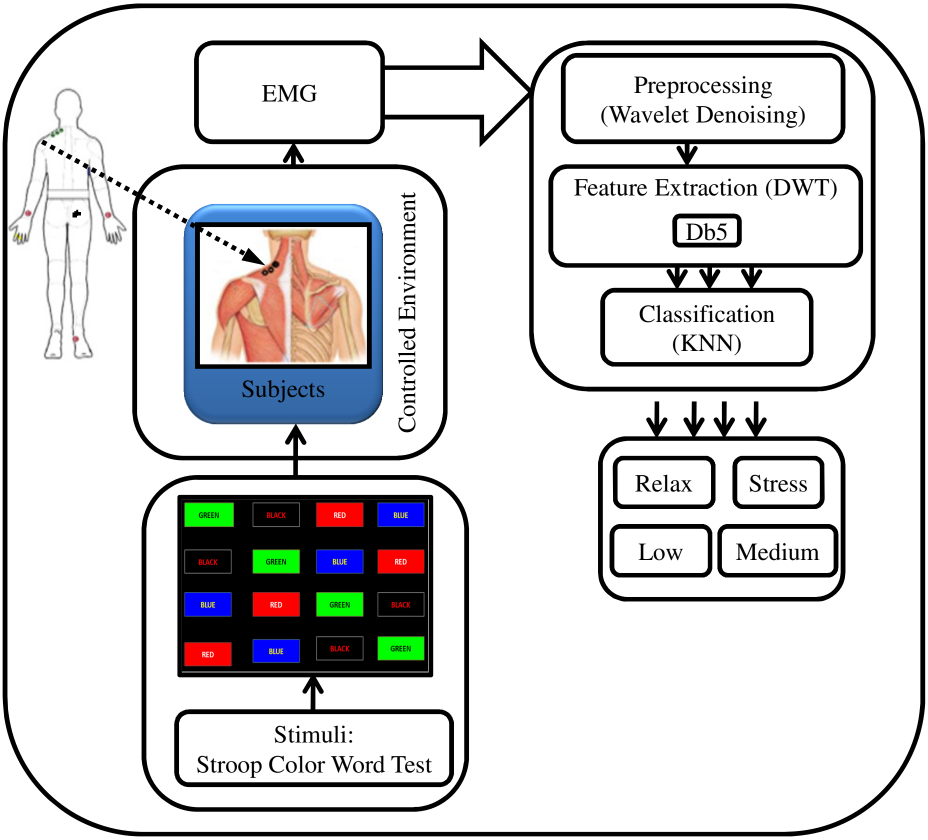

Fig. 1. Research methodology for stress assessment using EMG signals

2.2 Wavelet Packet Transform

The Discrete Wavelet Transform (DWT) has been widely applied on several applications. Indeed, this transform is an efficient technique to analyze the input signal both in time and frequency domain. DWT has the filter bank structures for decomposing the input signal. However, DWT only decomposes low frequency components into further levels. Wavelet Packet Transform (WPT) is used for analyzing the input signal in both low and high frequency information's of the input signals. Fig 2 shows the operation of filter bank implementation of WPT. Hence, WPT is considered to localize the frequency bands in large frequency range signals like EMG signal (0-2000) Hz, which is usually in the applications of gait analysis, and muscle rehabilitation studies. Similarly, Fig.3 illustrates the original sub signal in vector subspace (round shapes), which indicates the uniform frequency division with equal frequency resolution. X[n] is the representation of raw signal, H1[n], H2[n],.... Hn[n] and G[n], G2[n],.... Gn[n] is the the approximation and detailed coefficient of wavelet packet transform. Which is also called the low pass and high filters coefficient of WPT. Similarly, W_{00}, W_{10},.....W_{nm} indicates wavelet coefficients in the n^{th} level of m^{th} frequency band.

According the Nyquist criteria, in this research an acquired EMG signal can be analyzed up to 250 Hz. Table 1 presents the details about the frequency ranges respective decomposition levels. In this work, WPT coefficients in third and fourth levels are considered for analyzing the input signal ranging from (0 – 250) Hz.

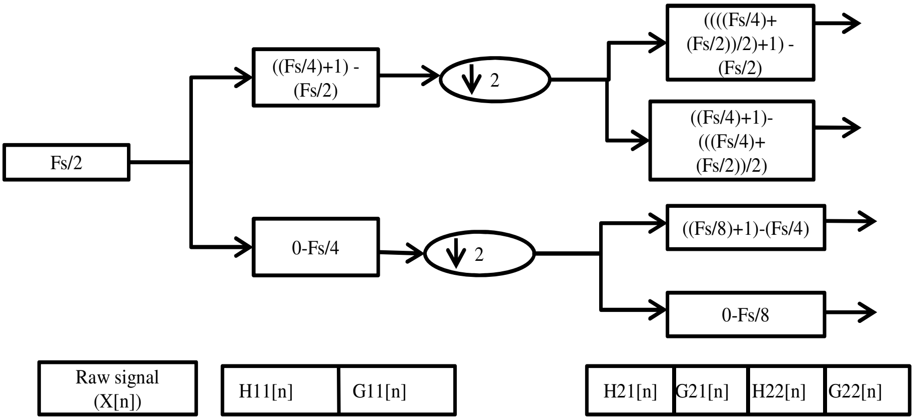

Fig. 2. Filter structure and cutoff frequency WPT in each level

Totally, 24-frequency bands (8 bands in level 3, 16 bands in level 4) have been derived from the input EMG signal for classifying the stress levels of the humans.

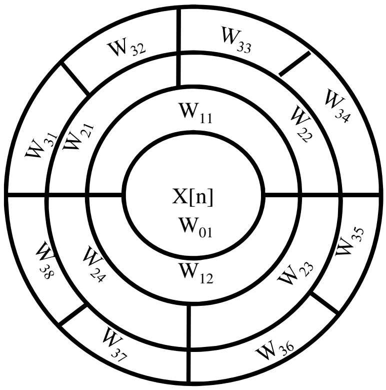

Fig. 3. WPT in each level Equal frequency band of represented in vector sub space

2.3 Feature Extraction and Normalization

Selection of most appropriate frequency band information from the input signal is highly useful for minimize the computation complexity, computation time, and to increase the classification rate. Previously, The EMG signal frequency from (0– 16) Hz is analyzed for estimating the stress levels in car drivers [6]. In addition, another studied are sampled the signal at 10 KHz [13]. In this work, signal was sampled at 500 Hz for detail investigation and to localize frequency bands. Seven basic statistical features such as minimum maximum, mean, standard deviation, power, energy and entropy of wavelet packet transform coefficients are derived from each frequency band in level 3 and level 4. 180 sec relax data were windowed into 5.625 sec of 32 epochs for trail and obtained the total of 640 feature vector of 2 trails over the 10 subjects. Similarly, Table 2 shows the remaining level time and feature information's.

Table 1. Frequency band information on each level of 500Hz sampled signals

Raw Signal		Level 1		Level 2		Level 3		Level 4	
Frequency range	Label of the band	Frequency range	Label of the band	Frequency range	Label of the band	Frequency range	Label of the band	Frequency range	Label of the band
0-250	W_{01}	0-125	W_{11}	0-62.5	W_{21}	0-31.5	W_{31}	0-15.63	W_{41}
								15.625-31.25	W_{42}
						31.5-62.5	W_{32}	31.25-46.88	W_{43}
								46.875-62.5	W_{44}
				62.5-125	W_{22}	62.5-93.75	W_{33}	62.5-78.13	W_{45}
								78.125-93.75	W_{46}
						93.75-125	W_{34}	93.75-09.4	W_{47}
								109.375-125	W_{48}
		125-250	W_{12}	125-187.5	W_{23}	125-156.25	W_{35}	125-40.6	W_{49}
								140.625-156.3	W_{410}
						156.25-187.5	W_{36}	156.25-171.9	W_{411}
								171.875-187.5	W_{412}
				187.5-250	W_{24}	187.5-218.75	W_{37}	187.5-203.1	W_{413}
								203.125-218.8	W_{414}
						218.75-250	W_{38}	218.75-234.4	W_{415}
								234.375-250	W_{416}

Table 2. Statistical feature computation from EMG signals over four different stress levels

States	Duration	Duration of epochs	Total number of epochs in each state	Total number of features in two trails	Total number of features in each class
Relax	180 sec	5.625 sec	32	64	640
Low	128 sec	4sec	32	64	640
Medium	64sec	2sec	32	64	640
High	32 sec	1sec	32	64	640

2.4 K Nearest Neighbor Classifier

KNN is well known discriminator for classifying different features. This classifier works based on the distance between the query scenario (features) and set of scenario in the data set (class) [7]. In this work, seven statistical features calculated over the 24 frequency bands in level 3 and level 4. The 430080 (24 features*7 features * 640 vectors in each class*4 class) feature vectors of all the subjects including all the classes were computed. Each feature consists of 2560 vectors and in Training phase 60% (1536) data were given to KNN and 40% (1024) data were tested. This method does not require building up any model and it completely works on local information (nearest training points). This method is also called as “instance-based learning”. The minimum K value indicates the features are exactly fitted with class. In this work, K value is tested from 1 to 10 and best value of K and its relevant classification accuracy is reported in section 3.

3 Results and Discussion

3.1 Recognition of Stress Levels

Recent way to analyze nonlinear EMG signal have demonstrated in human stress research. Measurement of involuntary muscle activity in cardiac region explored using advanced signal processing techniques. Total of 24 different frequency band with 7 simple features of EMG signals were analyzed. Result indicates that one frequency band is produced the maximum classification accuracy up to 90.7%. This highest accuracy is obtained in minimum features whilst k is 5 in the frequency range of (0– 31.5) Hz in level 3 (W_{30}) which is shown in Table 3. This identifies WPT is an effective for investigating the performance of large frequency ranges of EMG signals in other application like gait analysis, rehabilitation etc.

In order to discuss more detail, Results of two frequency bands related to (0 – 31.5) Hz are analyzed and such frequency bands are adjacent and two equal half of frequency range (0– 31.5) Hz. The results of those frequency bands are (W_{31}), (W_{40}) and (W_{41}) ((31.6 – 73) Hz, (0 – 15.8) Hz and (15.8 – 31.6) Hz) are also included in Table 3.

Table 3. Result of various frequency bands using KNN classifier

Frequency bands	Feature	K Value	Relax	Stress			Average accuracy
				Low	Medium	High	
(0-15.8) Hz	Minimum	10	98.49	84.27	61.25	84.32	82.08
(15.8-31.6) Hz	Minimum	10	43.44	31.25	45.57	74.43	48.67
(0-31.6) Hz	Minimum	**5**	**93.49**	**86.93**	**92.50**	**89.90**	**90.70**
(31.6-73) Hz	Mean	9	51.82	65.63	73.54	91.30	70.57

The result shows the significant reduction in the frequency band (31.6 – 73) Hz of level 3. In this frequency range, the mean features only produced the maximum accuracy 70.57% rather than minimum feature. It desires the obtained recognition rate is inadequate to measure the stress.

Similarly, the first two frequency band in level 4 are (0 – 15.8) Hz and (15.8 – 31.6) Hz) produced the maximum classification rate of 82.08 % and 48.87% respectively. (0 – 15.8) Hz is produced maximum rate than (0 – 15.8) Hz which is the first and second of second half (0 – 31.5) Hz, and first (W_{40}) and (W_{41}) second frequency band of level 4.

3.2 Analysis of Minimum Feature

In this present work, a simple statistical feature called "minimum value" of WPT coefficients on various stress levels with relaxation state gives the maximum accuracy in stress assessment. Fig 4 describes the average minimum value of all subjects in each class. Minimum value is gradually reduced from 0.0403 to -626.33 of relax and high stress levels. However, the individual variations between the subjects are the reason for reduction of classification accuracy.

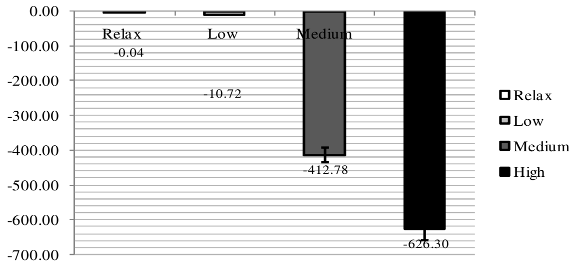

Fig. 4. Overall response of Minimum feature in (0 -31.5) Hz

4 Conclusion

This present work concludes the different levels of the using EMG signals. Initially, the stroop colour word test based stress inducement was done in a controlled environment with minimal surrounding disturbances. Wavelet Packet Transform is used for extracting the features over the 24 different frequency bands of preprocessed EMG signals. Among the different frequency bands, the frequency band information from (0– 31.5) Hz gives a maximum average stress level classification rate of 90.70% compared to other frequency bands. It implies that, the muscle activity under lower frequency range is highly useful for investigating the autonomic nervous system activities, specifically on stress assessment. In this work, we have only investigated seven simple features of WPT coefficients. Perhaps, the statistical features related to EMG signal characteristics such as mean absolute value, Wilson amplitude, kurtosis might be improve the average classification rate on stress level classification.

In future work, we will focus on investigating the EMG signals using different mother wavelet functions, statistical features, and classifier for enhancing the this research. In addition, so far we tested only with 10 subjects. In future, this population size will be increased to improve and validate our research methodology using some other advanced features.

Acknowledgments. This project work is financially supported by Ministry of Higher Education (MOHE), Malaysia through Fundamental Research Grant Scheme (FRGS). Grant Code: 9003-00341.

References

1. Frey, R.J.: Stress (2012), http://www.minddisorders.com/Py-Z/Stress.html#b (cited June 2 2012)
2. Tulen, H.M., et al.: Characterization of Stress Reactions to the Stroop Color Word Test. Pharmacology Biochemistry & Behavior 32(1), 9–15 (1989)
3. Ushiyama, K., et al.: Mental Physiologic Neuroendocrine Arousal by Mental Arithmetic Stress Test in Healthy Subjects. The American Journal of Cardiology 67, 101–103 (1991)
4. Knowledge Weavers Project -ECG, http://library.med.utah.edu/kw/ecg/ecg_outline/Lesson1/lead_dia.html
5. Hassellund, S.S., et al.: Long term stability of cardiovascular and catecholamine responses to sress tests an 18- year follow - up study. Journal of American Heart Association 55, 131–136 (2010)
6. Healey, J.A., Picard, R.W.: Detecting stress during real-world driving tasks using physiological sensors. IEEE Transactions on Intelligent Transportation Systems 6(2), 156–166 (2005)
7. Karthikeyan, P., Murugappan, M., Yaacob, S.: ECG signals based mental stress assessment using wavelet transform. In: 2011 IEEE International Conference on Control System Computing and Engineering, ICCSCE (2011)
8. Lundberg, U., Melin, B.: Psychophysiological stress and emg activity of the trapezius muscle. International Journal of Behavioral Medicine 1(4), 354–370 (1994)
9. Pehlivanoglu, B., Durmazlar, N., Balkanci, D.: Computer Adapted Stroop Colour-Word Conflict Test as a Laboratory Stress Model. Erciyes Medical Journal 27(2), 58–63 (2005)
10. Zhai, J., Barreto, A.: Stress Detection in Computer Users Based on Digital Signal Processing of Noninvasive Physiological Variables. In: 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS 2006 (2006)
11. Karthikeyan, P., Murugappan, M., Yaacob, S.: A review on stress inducement stimuli for assessing human stress using physiological signals. In: 2011 IEEE 7th International Colloquium on Signal Processing and its Applications, CSPA (2011)
12. Waested, M.: Attention Related Muscle Activity. National Institute of Occupational Health, Oslo (1997)
13. Lundberg, U., et al.: Effect of experimentally induceed stress on motor unit recruitment in the trapezius muscle. Work and Stress 16(2), 166–178 (2002)
14. Karthikeyan, P., Murugappan, M., Yaacob, S.: ECG Signal Denoising Using Wavelet Thresholding Technique in Human Stress Assessment. International Journal on Electrical Engineering and Informatics 4(2) (2012)