ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

A Wearable Cervical Fatigue Monitoring System Based On Multi-sensor Data

Weizhe Zhang, Shuohan Wang, Nan Bao [*], Wenbin Li

Northeastern Univeristy, School of Medicine and Biological Information Engineering, Shenyang, Liaoning, China
[*]Corresponding Author

ABSTRACT. *With the increase of social pressure and work intensity, fatigue has affected people's health. This paper developed a wearable fatigue monitoring system based on multi-sensor to detect the fatigue of the cervical vertebra. The monitoring system was worn on the user's neck, and the electromyographic signals (EMG) and the six-axis acceleration signals are collected and analyzed with the system. The time and frequency domain signal features were extracted. In order to detect the fatigue condition, the support vector machine (SVM) classifier was used involving 1800,000 labeled EMG data. In addition, the inclination angle of cervical vertebra can be obtained by the six-axis acceleration signal. It is proved that the fatigue monitoring system can effectively detect the fatigue of the cervical vertebra and warn the users*

KEYWORDS: *fatigue monitoring; the electromyographic signal; the six-axis acceleration signal, wearable system , support vector machine*

1. Introduction

With the change of people's life style and the increasing social pressure, the fatigue has become a threat of human’s health[1]. Long hours on the paperwork will cause the fatigue of the cervical vertebra and cervical spondylosis[2]. The fatigue of the neck often leads to further illness, pain, dizziness and some other symptoms of discomfort, and greatly affect the quality of life[3]. Therefore, it is necessary to timely detect and warn the fatigue of cervical vertebra. Nowadays, with the widespread wearable device application in home health monitoring, the development on the fatigue detection device has a good application value. Over the past few years, several related systems have been developed. Some systems, based on video images, used real-time data analysis to detect changes in the head position to determine the pressure of the cervical spine. However, it would expose the user's privacy. Other systems used the wearable sensors to detect the fatigue. Deng [4] used a six-axis acceleration sensor to calculate the inclination angle of cervical vertebra and judged the its fatigue degree. Liu[5] used sensors to obtain the cervical

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

motion angle and calculated the cervical motion volume. However, few of them used the combined detection with the electromyographic (EMG) signals and the six-axis acceleration signals for the fatigue of the neck.

This paper developed a wearable fatigue detection system based on EMG sensor and six-axis acceleration sensor. It collects EMG signals and six-axis acceleration signals of the neck through the hardware. The signals are pre-processed to remove the noise. Then the fatigue features of these signals are extracted, and the fatigue classification is trained based on support vector machine (SVM). Finally, the fatigue situation of the neck is determined.

2. Methodology

2.1 System hardware and signal acquisition

The developed system is based on multi-sensor, and the hardware part is consisted with the Arduino uno development board, the MPU-6050 six axis acceleration sensor, MyoWare™ Muscle Sensor (AT-04-001) and Hc-05 Bluetooth master-slave machine module. The six axis acceleration sensors are fixed the posterior of the cervical vertebrae, and myoelectric sensors are fixed on the trapezius muscle. Figure 1 and 2 show the waveforms of the EMG and six-axis acceleration signals collected by our system.

2.2 Signal preprocessing

In the paper, the Butterworth filter has been used to filter the noise in the EMG signals and six axis acceleration signals. The Butterworth band elimination filter can filter out the power interference of 50Hz [6, 7]. Due to its good local time-frequency analysis capability, wavelet transform has incomparable advantages in the traditional noise reduction methods [8, 9]. In this system, Wavelet transform is applied to denoise EMG signals and extract the features of the signal in time domain and frequency domain.

In addition, the developed system needs to calculate the change of the angle according to the six-axis acceleration signals collected by the six-axis acceleration sensor. Kalman filter is used as an algorithm to estimate the state of a linear system through the input and output of the system. Kalman filter can estimate the state of the dynamic system from a series of data with measurement noise when the measurement variance is known. In this system, Kalman filter is applied to denoise acceleration sensor signal and calculate the angle of neck.

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

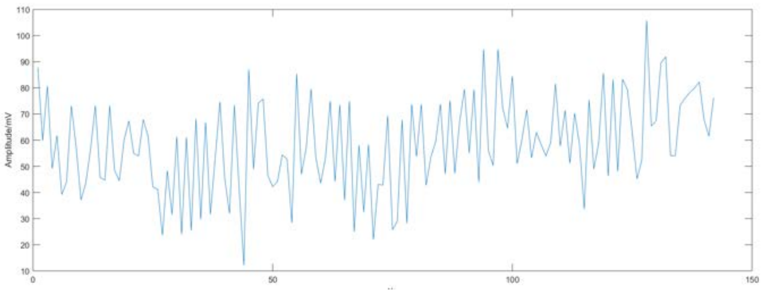


Figure 1.1EMG signal

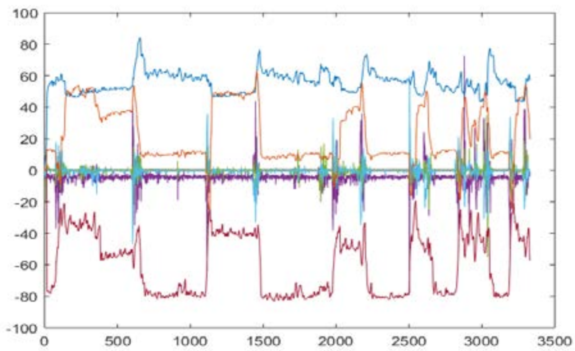


Figure 1.2 Six-axis acceleration signals

2.3 Cervical vertebra fatigue detection

The features of EMG signals can be summarized as time-domain features, frequency-domain features and time-frequency features [10]. The Integral EMG (IEMG) value of EMG signals is an important time-domain feature which can reflect the degree of muscle fatigue[11], which we used in our method. With the increase of the duration of the cervical bending, the muscles became tense and fatigue. More motor units were involved in the action, and the amplitude of EMG signal increased[12]. Then, the energy consumption of the muscle motor units increased, thus the IEMG increased. The comprehensive IEMG indexes are shown in table 1. The waveforms of the IEMG before and after fatigue are shown in figure 3. Through a large number of experiments, researchers have revealed that the power spectrum generally shifts from high frequency to low frequency with the fatigue of the muscle. The values of the mean frequency (MF) and mean power frequency(MPF) show a downward trend with the cervical fatigue, which are also used in our fatigue detection method [13].The IEMG, MF and MPF can be presented as follows:

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

$$MF = \sum_{i=1}^{N} \frac{f_i p_i}{2N} \tag{1}$$

$$MPF = \sum_{i=1}^{N} \frac{f_i p_i}{\sum_{i=1}^{N} p_i} \tag{2}$$

$$IMEG = \frac{1}{N} \sum_{i=1}^{N} |X_i| \tag{3}$$

where, pi is the estimated value of unit power spectrum (power spectrum density), N is the number of samples. The peak factor can be used to detect whether there is an impact in the signal. So, the fatigue feature vector matrix is consisted in the three features mentioned above. Then, SVM was used to classify the fatigue situation of the cervical vertebra based on the EMG signals. SVM is a generalized linear classifier that classifies data according to supervised learning methods. Its decision boundary is the maximum edge hyperplane of the learning sample [14-16]. Based on the feature matrix, SVM was used to train the EMG data set, and the neck fatigue classifier was obtained. The cervical fatigue can also be caused by prolonged bow desk. So, the system also detected the user's cervical curvature angle with the six-axis acceleration sensors to detect fatigue of the cervical vertebra. We defined that the maximum of the cervical curvature angle and extension of the cervical spine in three basic anatomical planes were X-axis plane, left flexion and right flexion were Y-axis plane, left and right rotation were z-axis plane. When the angle of the cervical is greater than the specified threshold for 10 minutes, it is defined as a fatigue sample. The device is worn on the user's neck. Based on the original data of six axis acceleration, the method of Kalman filter is used to calculate the cervical curvature angle of XYZ axis, and the threshold method is used to judge the incorrect posture of the cervical spine to remind the user.

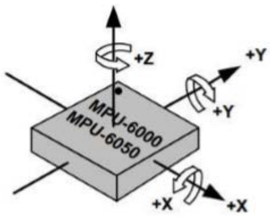


Figure 2. Diagrammatic sketch

The acceleration sensor is worn around the neck to obtain information about the

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

position of the human cervical vertebra. Therefore, according to the threshold value of cervical inclination Angle, it can help to judge the degree of cervical fatigue.The threshold values of cervical curvature angle with the improper postures which will cause the fatigue of cervical vertebra are shown in table2. The triaxial acceleration and angular acceleration should do not change in the initial static state, and the calibration is zero. Considering that the installation position of each sensor is different, the calibration function is added to the system, which can make the initial output angle return to zero for the convenience of subsequent data processing. Because the output data of the system tends to be stable for a while, signals for the first 1 minutes are read and calculate the per axis average value, which is saved as the base. The average value is saved as a benchmark, and later output data is different from the benchmark in the future. The offset of the system for the initial rotation state can be obtained.

If one of the EMG and the six axis acceleration signals are detected as the fatigue condition, the system will give the user an orange alert. If both of them are detected as the fatigue condition, the system will issue a red warning to the user.

Table 1. The threshold values of Integral EMG parameters were compared before and after muscle fatigue

	Left Neck (Standard deviation)	Right Neckl (Standard deviation)
Before fatigue	0.187	0.146
After fatigue	0.218	0.155

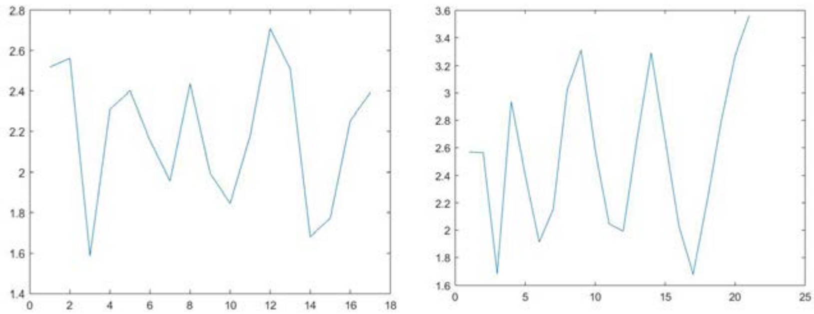


Figure 3. Integral EMG of subjects with normal(left) ang tired(right) muscle activity

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

Table 2. The cervical curvature angle of the improper posture

Category	Improper posture
X axis Angle	|Angle_accx|>30 degrees
Y axis Angle	Angle_accy>135degrees Angle_accy<75 degrees
Z axis Angle	Angle_accz>135 degrees Angle_accz<-15 degrees

3. Results and analysis

3.1 System hardware and experiment setting

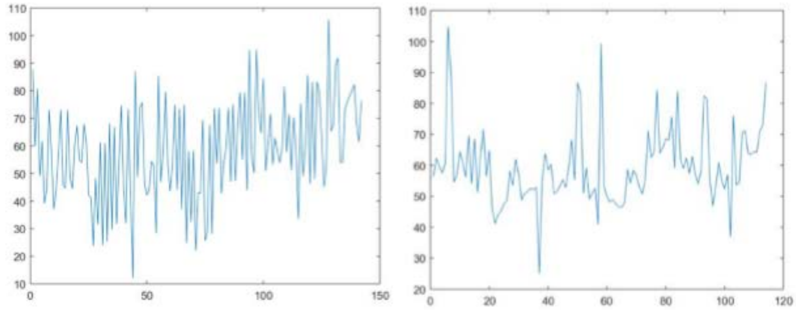
The prototype of the system and the wearing scene are shown in the figure 4. There are 10 subjects (aged 20±3 years, 167±5cm in height and 65±3kg in weight) involved in our experiment to verify the performance of the system. In order to simulate the cervical fatigue, the subjects were asked to perform the neck bending experiment. All the subjects have no symptoms of neck disease. The experiment time is the same period, and the temperature and humidity are controlled by air conditioning. The superior trapezius muscle (UT) was selected to paste the electrodes of the EMG signals. According to the anatomical position of the muscle and the direction of the muscle fibers, the electrodes were attached to the superior trapezius muscle 3cm away from the C7 spinous process, and the reference electrode was placed at the C7 spinous process. In order to ensure effective, the skin is sterilized with medical alcohol. The system collected 1800000 sets of myoelectric EMG signals and acceleration signal. Each EMG signal lasts for two hours and the sampling frequency is 500Hz. The EMG signals in initial 0~30 min were defined as non fatigue sample(negative sample). The EMG signals in 90 ~ 120 min is treated as the fatigue situation(positive sample).

Figure 4. The hardware of the system

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

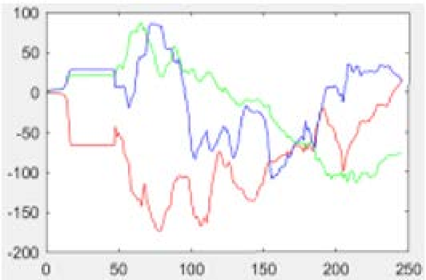
3.2 Signal preprocessing

The system uses the Butterworth filter and the Wavelet filter to denoise EMG signal shown in figure 5. The Kalman filter is used to calculate the attitude angle based on the triaxial acceleration and angular acceleration signals shown in figure 6.

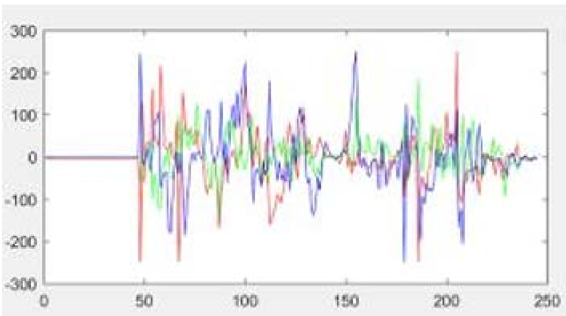


(a) *(b)*

Figure 5. Original EMG signal(a) and the butterworth and wavelet filter signal (b)

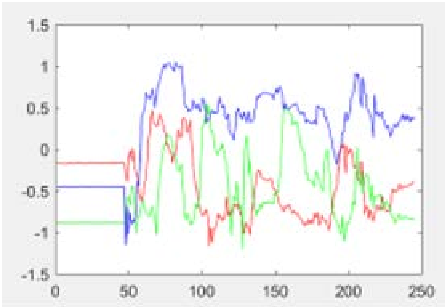


(a) Triaxial acceleration



ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

(b)Angular acceleration



(c) Filtered Angle

Figure 6. The calculation of the attitude angle based on Kalman filter

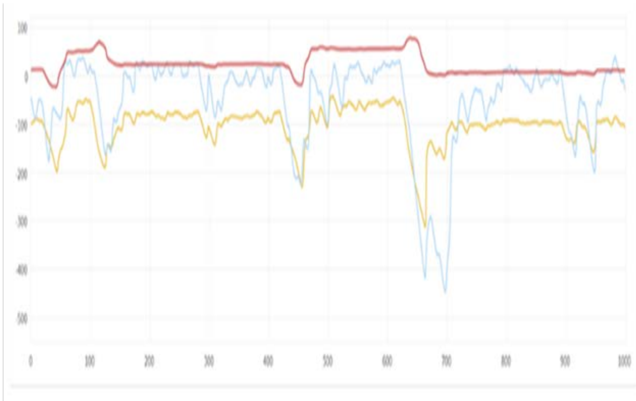


Figure 7. After Kalman filter Attitude angle

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

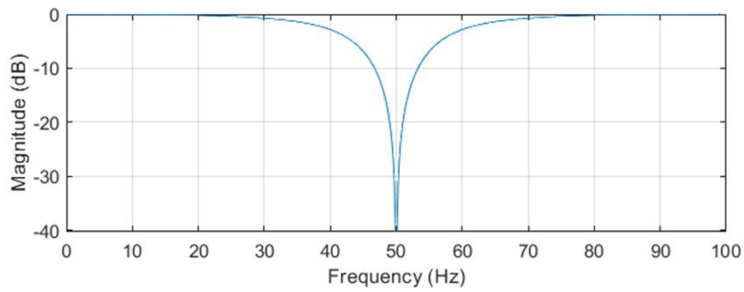


Figure 8. The Butterworth filter

3.3 Fatigue detection accuracy

In this system, the collected EMG signals of the neck are used as the training samples to train the cervical fatigue classifier, and the ten-fold cross validation method is used to test the accuracy of the classification. Three features of EMG are calculated, including IEMG, MF and MPF. The training set is consisted in 18,000,000 cases, including 900,000 cases of non-fatigue samples and 9,000,000 cases of fatigue samples. The detection results are shown in the table3 and 4.

Table 3. Classification results based on EMG database

Database / Classifier	Fatigue Samples	Nonfatigue Sample
Fatigue Samples	7367145	1578243
Non-fatigue Sample	1632865	7421767

Table 4. Classification results evaluate

Indicators	Accuracy	False positive rate (FPR)	False negative rate (FNR)
	82.16%	18.03%	17.64%

$$\text{Accuracy} = \frac{\sum True\ positive + \sum True\ negative}{\sum Total\ data} \qquad (4)$$

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

$$FNR = \frac{\sum False\ negative}{\sum Condition\ positive} \tag{5}$$

$$FPR = \frac{\sum False\ positive}{\sum Condition\ negative} \tag{6}$$

The experimental results show that the classifier used in this paper has good classification performance. But the system still leaves much to be desired. The target audience is college students. The experiment should select a certain number of subjects from each group. Because the experimental equipment is wrapped around the neck, the local temperature of the neck during the experiment will be higher than normal state. Because MP and MPF of EMG signal will decrease with the increase of temperature, there will be some errors in fatigue detection. During the test, some of the subjects were overstrained due to the white coat effect.

At the same time, we carry out the fatigue detection based on the six axis acceleration sensor. It was found that 8441259 fatigue samples were detected when the inclination of the neck was more than the threshold value for 10 minutes. It can be seen that the method to judge cervical fatigue based on six axis acceleration signal is reliable

4.Conclusion

Now, the cervical fatigue has seriously affected the human health. An intelligent monitoring system of the fatigue of the cervical spine can effectively promote the quality of people’s life. In this paper, a wearable cervical fatigue detection system is developed based on the EMG signals and six-axis acceleration signals with the machine learning method. The experimental results show that the system is effective for the detection of the cervical fatigue. However, we still have many points to be improved. In the future, we will adopt the method of deep learning to classify the cervical fatigue and improve the accuracy of detection.

References

[1] Zang Qian,Wu Zheng jun. Advances in Chinese and western medicine research on chronic fatigue syndrome. Journal of Chinese medicine，2012
[2] Li YuanShi. Study on the features of muscle surface emg signals in people who work at a desk for a long time. Tianjin university of science and technology, 2015.
[3] Song Yaguang. Observation on 85 cases of neck fatigue treated by fengchi warm acupuncture. Clinical journal of acupuncture and moxibustion,1998
[4] Deng Kailian, Zhou Zhipeng. Design of intelligent attitude monitoring device for prevention of cervical spine disease. Application of single-chip microcomputer and embedded system,2017.
[5] Liu Xueqiang. Devices and wearable devices for measuring cervical mobility. The AAAI conference on artificial intelligence, 2000.

ISSN 2618-1584 Vol. 2, Issue 1: 1-11, DOI: 10.25236/FMSR.2020.020101

[6] Song Kunpo, Xia Shunren, Xu Aing. Ultrasonic image noise reduction algorithm considering wavelet coefficient correlation. Journal of Zhejiang university (engineering science edition), 2010,44 (11) : 2203 2208.

[7] AWAL M A，MOSTAFA S S，AHMAD M，et al. An adaptive level dependent wavelet thresholding for ECG denoising. Biocybernetics & biomedical engineering，2014，34（4）：238-249.

[8] Huang Yuchang, Hou Dewen. Fingerprint image denoising based on improved wavelet threshold function. Computer engineering and application, 2014,50 (6) : 179, 181. (in Chinese)

[9] Wang Hongqiang, Shang Chunyang, Gao Ruipeng, et al. Improvement of wavelet threshold denoising algorithm based on wavelet coefficient transform. Vibration and impact, 2011,30 (10) : 165 168.

[10] Zhou Q X, Chen Y H, Ma C, et al. Evaluation model for muscle fatigue of upper limb based on sEMG analysis. Sci China Life Sci, 2011, 54

[11] Li Tao. Correlation analysis between center frequency of EMG power spectrum and muscle fatigue. Chinese journal of rehabilitation medicine, 1995,10 (4) : 153-155.

[12] Wang l, Sun g b, Guo w b. feature extraction of cervical surface EMG signal based on empirical mode decomposition. Journal of Shenyang institute of engineering (natural science), 2013,9 (03) : 272-274.

[13] Petrofsky JS， Lind AR． Frequency analysis of the surface electromyogram during sustained isometric contractions． European Journal of Applied Physiology ＆ Occupational Physiology，1980，43(2) : 173-182．

[14] Vapnik, V. Statistical learning theory. 1998 (Vol. 3). New York, NY：Wiley，1998：Chapter 10-11, pp.401-492

[15] Zhou Zhihua. Machine learning. Beijing: Tsinghua university press, 2016: pp.121-139, 298-300

[16] Li Hang. Statistical learning methods. Beijing: Tsinghua university press, 2012: chapter 7, pp.95-135