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Comparative Study of Electromyographic Signal in Stroke Patients

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Abstract

Stroke is a common condition among the elderly in high latitude and cold area. Its high occurrence, recurrence and disability rate makes it a serious threat for the health and life of middle to old age population, and a heavy burden for patient's family and the society as a whole. Surface electromyogram signal is a bio-electricity signal recorded from electrodes on muscle surface with controlled neuromuscular actions. It is a direct signal revealing muscle activity and function, and it can reflect neuromuscular activity to certain extent. This study focuses on the accumulated data of electromyographic signal recorded from human upper limb, using Matlab tool to analyze and compare neuromuscular signals between healthy population and stroke patients, finding characters of surface neuromuscular signals with mathematical methods such as Fourier transformation, Hilbert transformation and AR modelling, and then induce the changing pattern of neuromuscular signals with various physiological indicators and make prediction of muscular pathological tendency.

Keywords: *surface neuromuscular signal, stroke, Fourier transformation, Hilbert transformation, AR modelling*

1. Introduction

Electromyography (EMG) is produced in the complex process of bioelectricity generation during muscle excitation or activity, which has complex relationship with biochemical process, contraction process and neuromuscular control system of muscle tissue [1]. Neuromuscular control systems mainly communicate command signals with neural structures including cortical motor area, brainstem and medulla spinalis. Surface neuromuscular signal is widely used in clinical medicine, athletic medicine, ergonomics, restoration medicine, neurophysiology and electrophysiology. For example, Fougner (2013) used surface electromyography (SEMG) signal for the study of robust, coordinated and proportional myoelectric control of upper limb prostheses [2]. By placing electrodes on the surface of muscle group of interest and capturing SEMG signals, joint movement intensity and status can be reflected, as well as the movement of finger, wrist and elbow in the process real-time. SEMG is innately at advantage of fine movement recognition, combined with non-invasion and simple application characteristics, hand gesture

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recognition and interaction technology based on SEMG signals have become a current hotspot in human-machine interaction technology. Many researchers and institutes have initiated studies involving joint movement recognition and successfully applied in smart artificial limb and control interface (De Luca 1978; Fougner, *et al.*, 2012; Lenzi, *et al.*, 2012) [3-5].

SEMG signal is a specific, time-varying and non-linear weak electronic signal, its voltage ranges between 100-5000μV at 5-2000Hz. Surface neuromuscular signal recording is a simple, non-invasive process easily accepted by subjects, it is helpful not only in the reflection of muscle physiological and biochemical changes in movement but also in resting status; It is not only a meaningful diagnostic method for motion ability, but also a good technique for biological feedback treatment, therefore, it has important application value in clinical neuromuscular disease diagnostics and recovery, athletic fatigue judgment, sports technical rationality analysis, muscular fiber type, function and non-invasive anaerobic threshold determination. For example, Cai, *et al.*, used SEMG signal of upper limb in the study of Parkinson's disease patients [6], Dong, *et al.*, used pelvic floor SEMG signal for clinical symptoms of functional constipation in elderly patients [7].

Characterizing of SEMG is the fundamental process for further analysis. Many international studies suggest 4 specific characterizing method: time domain analysis, frequency domain analysis, time-frequency analysis and non-linear kinetic analysis. In this study, common methods are used for analysis, such as frequency characteristic focusing Fourier transformation, frequency energy focusing Hilbert transformation, and AR modelling which focuses on signal correlation in stable process.

Stroke (cerebral apoplexy or cerebrovascular accident, CVA) is a non-infectious chronic disease which is difficult to cure and threats patient's life [8]. Stroke or CVA causes acute damage to brain tissue, which usually happens when the blood vessel responsible for oxygen and nutrition supply is ruptured, damaged or blocked by blood clot or other particulate matter. Neural cells die in a few minutes if deprived of oxygen, body functions controlled by these neural cells are lost as a consequence. As dead brain neurons are unable to be replaced, the impact of stroke is usually permanent. In large-vessel acute ischemic stroke patient, 1.9 million neurons, 14 billion synapses and 12 km myelinated nerve fibers are lost every minute, or 120 million neurons, 8.3 trillion synapses and 714 km myelinated nerve fibers lost every hour. Compared to normal neuron death rate with brain ageing, one hour in stroke is equal to 3.6 years of ageing. According to 2011 China Cardiovascular Disease Report, only 10,000 patients were diagnosed as stroke in 1980, a Figure climbed to 2 million in 2008 at an increasing rate of 9% per year in China [9]. Recently, much progress has been made in stroke treatment, death rate is significantly reduced, but disabling rate is still high due to the lack of effective treatment method.

If the human body is considered as a complete physiological system, it is fully automatic with high efficiency and stability when enough supply (energy, food, water) is supplied. The brain is the most important control unit of the whole system, providing countless signals controlling all physiological activities including basic breathing, heartbeat and muscle movement. From control engineering perspective, every nerve impulse generated by the brain is a group of control signal carrying ample information, including detailed instruction on muscle movements. The information rely on the nerve system to pass on to the muscle, which is the final controlling element in this case. We can view brain-nerve system-muscle as a complete closed control system (Figure 1).

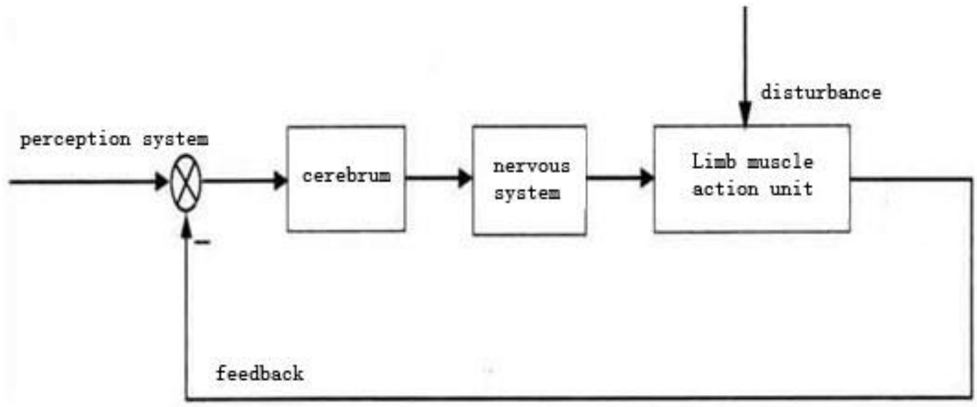

Figure 1. Schematic Structure of Human Control System

Human muscle surface has resting potential in complete stationary state, which is generated by potential difference across muscle cell membrane. When muscle is excited or needs to be activated, brain sends motion command to central nervous system and control muscle tissue via motor neurons for desired movement; on the other hand, muscle activity is affected by peripheral information obtained by central nervous system from muscle, which continuously coordinates the execution of the muscle motion [10]. The classical damage condition of stroke patient is poor muscle motor control and difficulty in walking initiation. As changes in SEMG signal characteristics can reflect central nervous system control factor and muscle excitation conduction speed to certain extent, it has been used in limb recovery assessment for a long time with its effective reduction of limitations in other unquantifiable objective assessments [11]. By recording changes of SEMG signals with various physiological indicators, and analyzing control and muscular motor signals using Matlab, we can deduce the pattern, further predict trend in muscle disorder, and build database by tracking SEMG signal in healthy population to analyze, predict and forecast diseases.

Stroke patients lose part or all brain signal control of organ and muscle as a result of acute brain damage after brain circulation is clogged, leading to sequel of hemiplegic paralysis. As the complexity of brain signals makes it difficult to collect, analyze and study, we used the other end of the controlling pathway, *i.e.*, SEMG signal of upper limb in this study. By comparing different SEMG characteristics of healthy population with stroke patients, we hope to decipher the code of human muscle movement, assist clinical treatment and eventually prediction of disease [12].

2. Problem Formulation

Research subjects in this study are healthy volunteers (collage students) and stroke patients admitted in Second Affiliated Hospital of Heilongjiang University of Chinese Medicine, department of acupuncture and moxibusition, the latter divided as cerebral infraction group and cerebral hemorrhage group. Non-invasive surface electrode patches are used to collect SEMG signals of upper limb, which is harmless to human body. Signals are collected using a PCI card through amplification, noise reduction and A/D conversion as input, then processed by dedicated program. Figure 2 shows original raw SEMG signal collected from upper limb, sampling frequency 25000Hz:

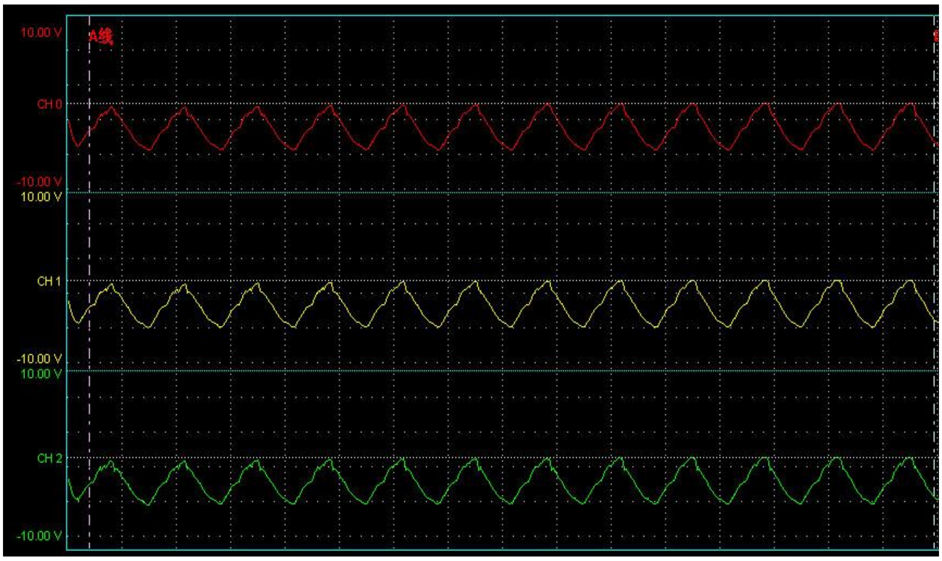

Figure 2. Upper Limb SEMG Signal of Healthy Male

In this study, we focus on the application of Matlab in analysis of physiological implication of different upper limb SEMG signals between healthy population, cerebral infraction and cerebral hemorrhage patients.

3. Analysis of Upper Limb SEMG Signal using Matlab

Matlab (Matrix Laboratory) is a software package developed by MathWorks since 1984, which is widely used in system simulation, digital signal processing, and image processing and scientific visualizing areas. Matlab Version 7.0 is used in this study.

Some possible characteristics of SEMG signals recorded are observable with bare eyes. In order to obtain more accurate results, assist diagnosis and treatment, muscle SEMG signals need to be processed with mathematical functions in Matlab. After importing the data into Matlab, raw data of three different groups are presented (Figure 3)

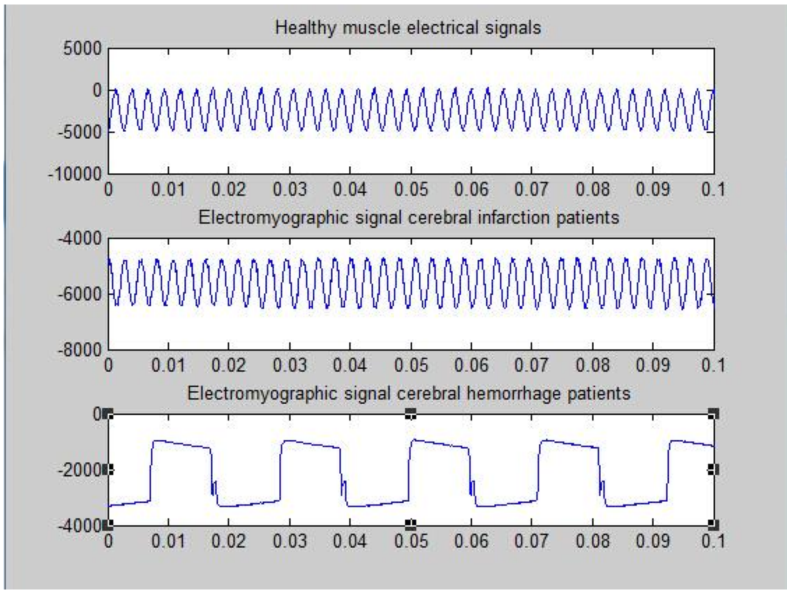

Figure 3. Raw SEMG Signal Comparison

Matlab clearly revealed differences unfound with bare eyes. SEMG signal amplitude from healthy population ranges between 0-5v (x axis represents data collected in 0.1s). Cerebral infraction patients lost action potential from part of the control signal stimulation, their signal amplitude is significantly reduced as a result. Cerebral hemorrhage patients almost lost all muscle control by the brain. A quantitative analysis will be used in upper limb SEMG signals in different population groups.

3.1 Analysis of SEMG Signal using Mean and Variance

Mean value is the average of a series of statistics or measurement, variance is the difference between the variable and its mean. By combining mean and variance, we can determine the consistency of a group of random variables, thus the suitability of prediction.

In Matlab, we can use mean (a) function for the mean value of random variable, var(a) for variance, a represents matrix consisting of random variable. By analyzing SEMG signals of some healthy volunteers and stroke patients, we found that the mean value of healthy group is around -2500, with variance between 2.5548e+006 to 2.9008e+006. The signal of stroke patients is much weaker and variance worse. However, after treatment with acupuncture, moxibusition and traditional Chinese medicine, their mean and variance value recovered to levels close to healthy group (Table 1):

Table 1. Grouped Data

Test Subject	Mean	Variance
Healthy 1	-2532.7	2.7994e+006
Healthy 2	-2506.4	2.8225e+006
Healthy 3	-2498.0	2.5548e+006
Infraction 1-pre treatment	-5621.1	4.2000e+005
Infraction 2-pre treatment	-7175.4	1.6527e+006
Hemorrhage 1-pre treatment	-2195.6	1.1046e+006
Hemorrhage 2-pre treatment	-3445.0	6.4328e+006
Infraction 1-post treatment	-3204.2	1.7554e+006
Infraction 2-post treatment	-3191.4	4.6973e+006
Hemorrhage 1-post treatment	-3154.8	8.1548e+006
Hemorrhage 2-post treatment	-3454.3	6.4432e+006

The mean and variance values of SEMG signals of healthy population are relatively stable. This suggests that SEMG signal in population with normal limb motor control is consistent. Stroke patients have weaker, very unstable SEMG signals and higher variance due to limb motor disorder. However, the characteristics of SEMG signals cannot be represented completely by the observation of mean and variance, other mathematical methods are required [13].

3.2 Analysis of SEMG signal with Fourier Transformation

Fourier transformation can convert a time-domain signal to characteristic frequency domain signal. In Matlab, a dedicated fft(a) function can directly process captured SEMG signal sequence. A Figure of magnitude-frequency characteristics can be drawn after Fourier transformation of SEMG signals (Figure 4):

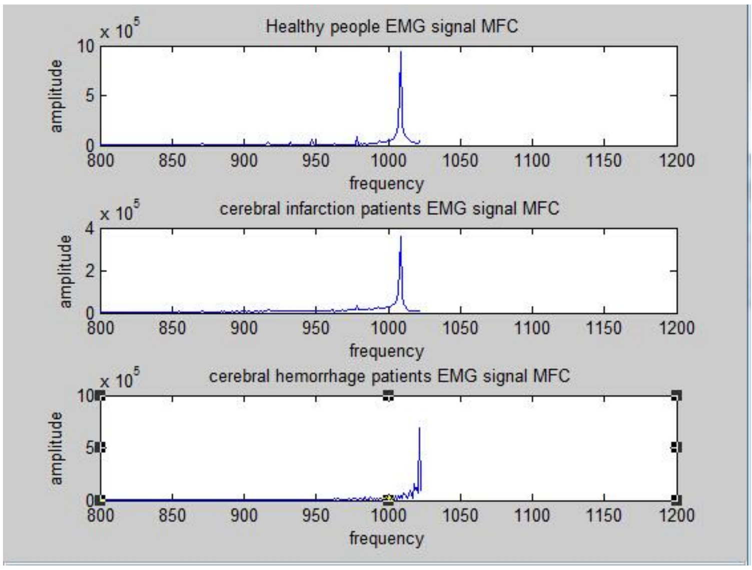

Figure 4. The Comparison of Magnitude-frequency Characteristics between Healthy Population and Stroke (Infraction and Hemorrhage) Patients (high Frequency Part)

After Fourier transformation, SEMG signal of healthy population is mainly concentrated between 10 Hz and 1000 Hz. In high frequency band around 1000Hz, the amplitude of healthy population is twice the value of stroke patients. Pathologically speaking, as neural damage of stroke patient is worsened gradually, early treatment on cranial nerve combined with high frequency signal compassion of acupuncture and moxibusition can greatly restore patients' nerve function. It is more complex to treat cerebral hemorrhage patients. Around 1000 Hz where normal SEMG signals function, almost no SEMG signals are detectable in hemorrhage patients; however, some signals are present in frequency band much higher than 1000 Hz. Further studies are needed to understand the implication of these signals

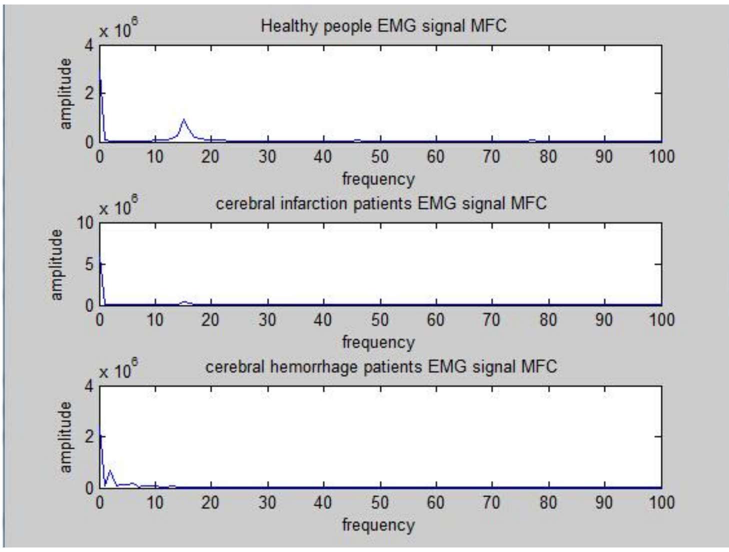

Figure 5. The Comparison of Magnitude-frequency Characteristics between Healthy Population and Stroke (Infraction and Hemorrhage) Patients (Low Frequency Part)

Similar conclusions can be made in lower frequencies. For working SEMG signal between 10 Hz and 20 Hz, stroke patients have much lower amplitude than healthy population. It is also the fundamental cause of motor disorder from control system point of view. Acupuncture and moxibusition treatment has significant effects in compensation of low frequency signals, as shown in Figure 6:

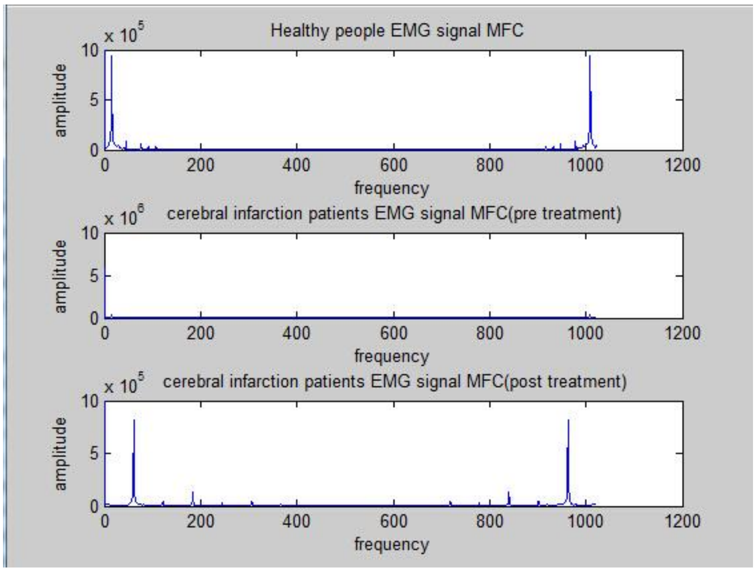

Figure 6. Comparison of Magnitude-frequency Characteristics between Healthy Population and Infraction Patients (Pre and Post Treatment)

After acupuncture and moxibusition treatment, the magnitude-frequency characteristics of infraction patient tend to move to that of healthy population. The rise in amplitude of SEMG signal is an indicator of muscular function recovery [14].

3.3 Analysis of SEMG signal using Hilbert Transformation

In recent years, envelope and kernel function is increasingly used in biomedical engineering. Hilbert transformation is an important method to obtain medical signal envelope. In this study, we used Hilbert transformation to analyze upper limb SEMG, as shown in Figure 7:

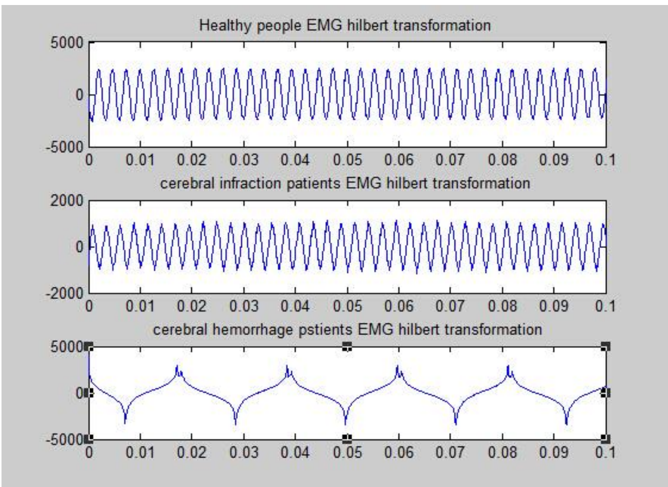

Figure 7. Hilbert Transformation of Healthy Population and Stroke (Cerebral Infraction and Hemorrhage) Patients

Although we can see from amplitude that cerebral infraction patient has much weaker SEMG signals than healthy population, their signal envelop have similarities. However, hemorrhage patients are completely different. We have reached preliminary conclusion that by using mathematical tool to analyze upper limb SEMG, it is possible to quickly determine the specific type of stroke patients. This conclusion is important in the fast diagnostic of stroke patients.

3.4 Analysis of SEMG Signal Correlation using AR Model

Human body SEMG signal is a smooth signal, which makes it possible to analyze with AR process modelling. We first obtained AR model function of healthy group, as shown in Figure 8:

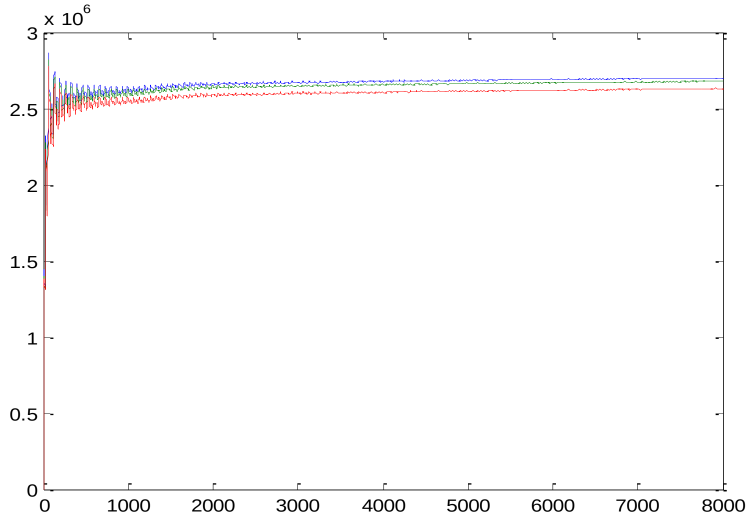

Figure 8. Correlation Function of AR Modelling in Healthy Population

From the Figure we can see rich information in AR modelling of healthy population SEMG signal. Third order correlation function is close and shows stable characteristic. It suggests that healthy people can complete physiological actions because brain control signals and motor control signals are stable on third or higher order of correlation function. Such signals have very good self-learning function. In the process of human body development, the repeated trial and learning of the same action makes it more proficient when performing complex actions. When this learning process is disrupted by loss of brain control signal as a result of external injury or brain damage, SEMG signals will become abnormal. Treatment is equivalent to shortening of the learning process, by using electrochemical signal generated by Chinese medicine and the electronic signal provided by stimulation of acupuncture and moxibusition. The Matlab programming of AR model is as below:

```
m=mean(b);
v=var(b)
y=(b-m)';time=7000;
 t=1:time;
 [cite,Qej]=rels(time,y,7);
 a1(1:time)=cite(1,1,1:time);
 a2(1:time)=cite(1,2,1:time);
 a3(1:time)=cite(1,3,1:time);
 Q(1:time)=Qej(1,1,1:time);
 plot(t,a1(t),t,a2(t),t,a3(t));Figure; plot(t,Q(t));
 m=1;
```



```
Re0(1:m,1:m,1:2)=0; Re1(1:m,1:m,1:2)=0; Re2(1:m,1:m,1:2)=0;
for t=2:time+18
    Re0(:,:,t+1)=Re0(:,:,t)+(1/(t+1))*(y(t+1)*y(t+1)'-Re0(:,:,t));
    Re1(:,:,t+1)=Re1(:,:,t)+(1/(t+1))*(y(t+1)*y(t)'-Re1(:,:,t));
    Re2(:,:,t+1)=Re2(:,:,t)+(1/(t+1))*(y(t+1)*y(t-1)'-Re2(:,:,t));
end
 t=1:time;Figure;
 R0(1:time)=Re0(:,:,1:time);
 R1(1:time)=Re1(:,:,1:time);
 R2(1:time)=Re2(:,:,1:time);
 plot(t,R0(t),t,R1(t),t,R2(t));
```

Where R is the correlation function of SEMG signals.

Different correlation function can be obtained using AR model to process the SEMG signals of cerebral infraction and hemorrhage patients, as shown in Figure 9, 10:

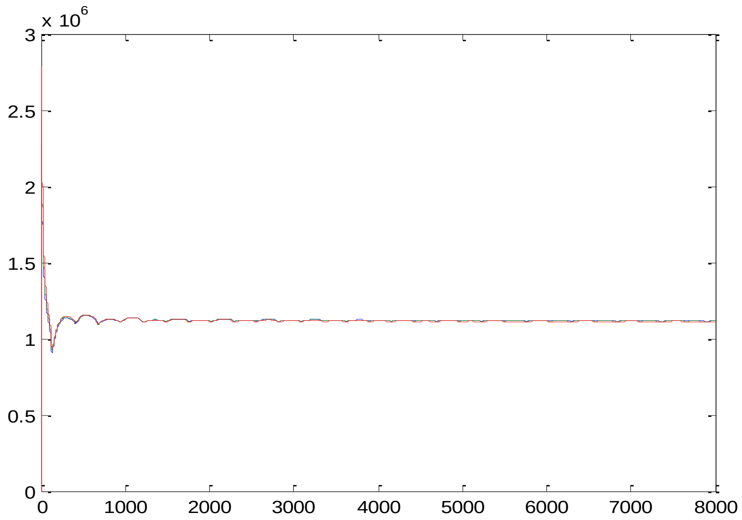

Figure 9. AR Modelling Correlation Function of Male Cerebral Hemorrhage Patient

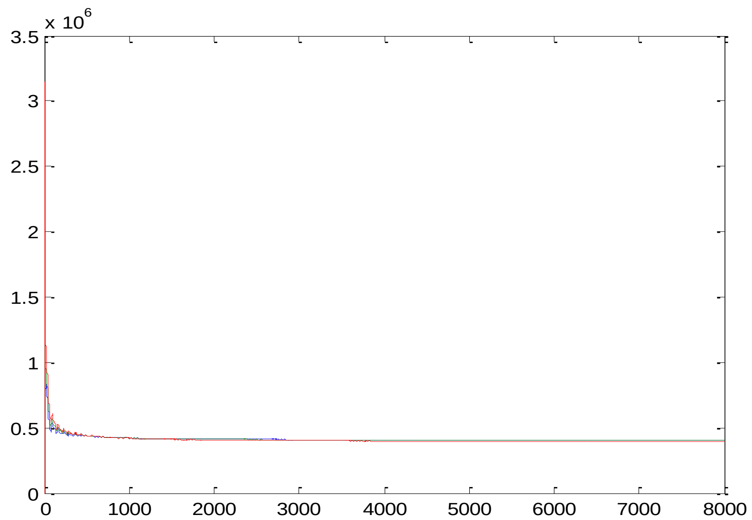

Figure 10. AR Modelling Correlation Function of Male Cerebral Infraction Patient

It is further concluded that AR modelling correlation function analysis of patient upper limb SEMG can quickly determine cerebral infraction or hemorrhage in the event of stroke, which has important clinical usage.

4. Conclusions

In this study, we used multiple Matlab tools to analyze upper limb SEMG signals of collected from healthy population and stroke patients. By intuitive analysis of raw data of upper limb SEMG signal, it is easy to distinguish between two types of stroke, *i.e.*, cerebral infraction and cerebral hemorrhage. By further processing raw data with Fourier transformation, amplitude-frequency frequencies can be obtained. Combining with Hilbert transformation and AR modelling of SEMG signals, we can further observe the different characteristics in different population groups and distinguish between different types of stroke.

In conclusion, multiple Matlab analysis of upper limb SEMG signals of stroke patients can quickly distinguish cerebral infraction and cerebral hemorrhage patients, providing mathematical basis of stroke treatment where every second counts.

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