The Review of Applications and Measurements in Facial Electromyography

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Received 4 July 2004; Accepted 23 Nov 2004

Abstract

In this paper, many applications related to facial EMG topics are reviewed and the current recommended practices are described. We have surveyed the facial EMG application on masticatory function evaluation, speech analysis and recognition, and emotional expression observation. In addition, we also introduce the measurement of facial EMG including the electrode selection; electrode position and noise reduction. Finally, we have brought up some comments and issues for further developments of facial EMG technique. The purpose of this paper is to point out a potential and novel research topic, facial EMG. We hope to raise the interest in this topic and bring up some inspiration for researchers studying facial EMG technique.

Keywords: Facial electromyography (fEMG), fEMG measurement, fEMG Application

Introduction

The face is the most important area in the body surface. Human face provides an interface for us to exchange the information with real world. All of the organs on the face could use to sense or present the message. For example, the eyes can obtain the image of surroundings, the ears can pick the sound, the tongue tastes the food savor, the nose can smell, and even the skin has the sense of touch. In the same way, we can give off the voice or speech from mouth, and facial muscle can express the emotion. In the process of information passing, the facial muscles play a dominant role to accomplish the information acquiring and message transmitting. We may, therefore, reasonably conclude that measuring the facial electromyography (EMG) will get much more useful information.

The following examples illustrate some potential applications performed by fEMG. The cerebration information including emotion, fatigue or feeling, could leak out from face. Facial motion disorders are also an early symptom in many diseases; such as the stroke patients may have the swallowing disorders in early stage. For the paralytic, who is resulted from the accident or illness, the facial muscle could be the last failed motor unit. Many prosthetic devices are controlled by this gateway. Therefore the facial EMG (fEMG) can provide valuable reference in clinic diagnosis and biomedical applications.

However, before applying fEMG to any application, we must consider the natural features of facial muscles. From the understanding of facial muscle kinematics, we know that the facial muscle is a small three-dimension combination of muscular slips carrying out a variety of complex orofacial functions. All facial functions, such as speech, mastication and facial expression, are all accomplished by individual muscles. A special neural feature of the facial muscles is that their contractions are not only under voluntary, but also emotional control[1]. Thus, a complete fEMG measurement requires simultaneous recording of multiple facial muscles. We also have to develop the measurement techniques and signal conditioning for dealing with the low SNR fEMG and every noise sources.

We hope this article can provide some helps to the people who are interested in facial EMG. The content of this paper includes (1) the description of the measurement problem in facial EMG (2) the discussion of the current application of facial EMG (3) discovering the potential application.

The Measurement of Facial Electromyography

This section will review the factors, which affecting the measurement of the facial EMG from the practical application. A general procedure to record the EMG signal can be divided into three stages (1) electrode selection and placement; (2) EMG recording; and (3) signal conditioning. We should carefully handle every stage to eliminate possible noise and to correct the measurement error. We need to carefully handle each stage and prevent the measurement error. We will discuss the noise source and noise reduction below.

2.1 Electrode Selection and Placement

The electrode is an important interface, which can pick up

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Table 1. The comparison for surface electrodes and inserting electrodes [5;6]

	Surface electrodes	Inserting electrodes
Advantages	1. Easy to use 2. Noninvasive 3. Large recording region 4. More safe 5. No hider movement	1. Capable of detecting MUAP 2. Better selectivity 3. High signal to noise ratio
Drawbacks	1. Only can measure the surface muscle EMG 2. Low signal to noise ratio 3. Poor selectivity 4. Artifact	1. Difficult to use 2. Invasive 3. Movement obstructing 4. Hazardous
Applications	1. The large muscle recording 2. Violent exercise	1. Single motor unit or small muscle recording 2. Recording the deep muscle

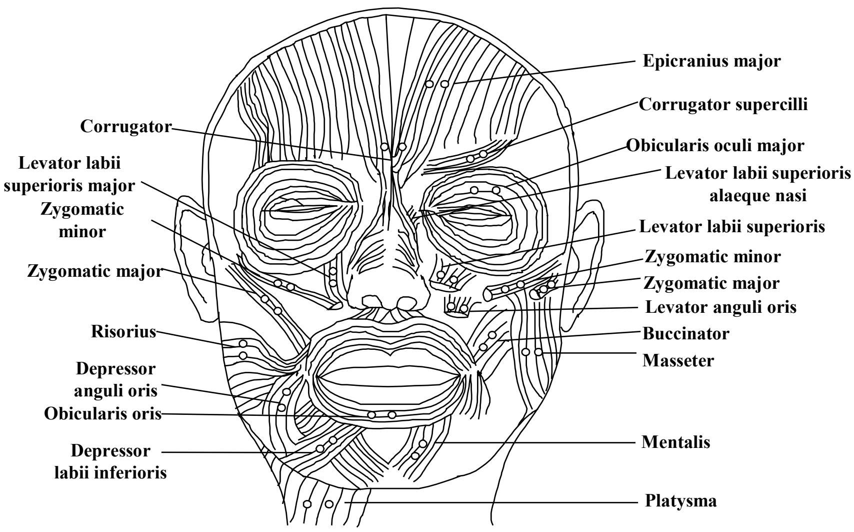

Figure 1. The location of facial muscles

the biopotential or the current in the human body, between the human body and measurement instrument. In the clinic test, two kinds of electrode are often used in EMG signal, surface electrodes and needle electrodes. Using needle electrodes can obtain good muscle selectivity and signal to noise ratio, so needle electrodes have been used in clinic diagnosis widely. In the other ways, the surface EMG signal usually contains the crosstalk signal originating from surrounding muscles. So it is difficult to analyze specific small muscle region by the surface EMG signal. But the surface EMG is very safe and easy to use. In the application of the fEMG, the safety issue is more important than the accuracy, so most people adopt noninvasive measurement, surface electrodes [2;3]. Table 1 lists the comparison between surface electrodes and inserting electrodes.

Besides the style of the electrodes, difference material of electrode can present greatly influence in the half-cell potential of electrode. In EMG measurement, all recording electrodes should be made of the same material to minimize half-cell potentials differences. Hermie et al. concluded that the circular electrode made by Ag/AgCl is most often adopted[4].

The electrode placement will influence the amplitude and spectrum of the fEMG signal. We need to put the electrode on the proper position to get the exact fEMG. The best site of electrode is located at the midline of the muscle belly[7]. However, the fibers of facial muscles usually are very thin and close to the facial tendon. Therefore finding the correct electrode position is not easy. This is also why fEMG amplitude is very weak. Lapati et al. suggested that we could find the detail muscle position by touching the contracting muscles[1]. Then the electrode can be located on the exact position. Figure 1 illustrates the facial muscle anatomy.

2.2 Noise source in fEMG measurement

Because the amplitude of fEMG is very weak, the signal is easily affected by external interference. In addition to electrode configuration we have mentioned above, there still exist many factors influence the accuracy of facial EMG. For instance, the 60 Hz power noise, electrostatic, radiation and the power supply variation, are all extrinsic noises[7].

The motion artifact is an often seen disturbance especially in surface EMG. This noise usually occurs when there is a relative motion between the electrode and attached skin. For example, the muscle contracting might cause the mechanical disturbance of the electrode charge layer. The movement of considered muscle would also deform the skin under electrodes. Above situations could result in the change of the

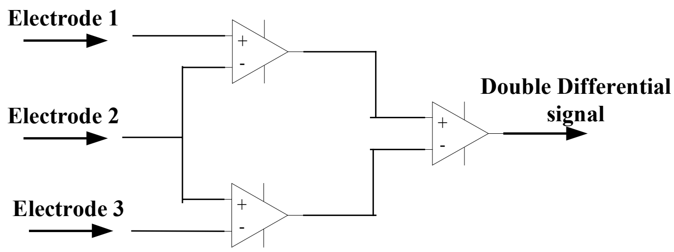

Figure 2. The architecture of double differential technique.

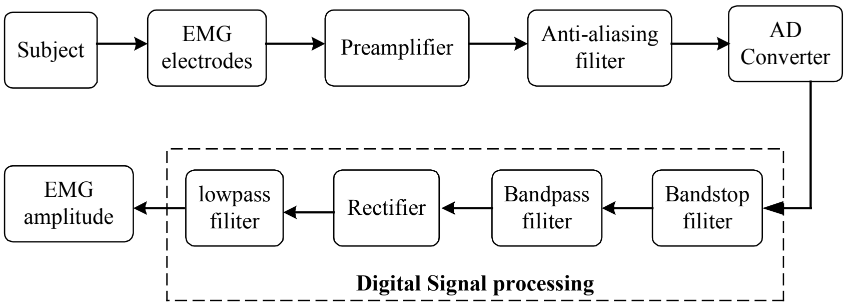

Figure 3. The EMG signal acquiring block diagram.

skin-electrode impedance and induce the measurement error. The most convenient method in reducing motion artifact is to use separating conductive gel. Any mechanical disturbances caused by relative motion between the electrode and skin, can be damped by the intermediate gel. In addition, the decreased skin impedance can also reduce the influence of impedance variation.

Power line interference is a serious noise source originating from power lines and electrical equipment. We could find out the power line interference by checking if frequency of the signal is the same as AC power supply and its harmonics. Because the magnitude of the power line interference could be much greater than the EMG itself, we need to carefully clear power noise in each measurement. We can easily remove this artifact by shielding the electrode lead wires and measurement devices. Moreover, the well attaching grounding electrodes and bipolar recording electrode would reduce any common mode signal, including power line interference.

The issues of crosstalk from adjacent muscles is important because the amplitude of the signal be analyzed is low and near the noise level. The likelihood of detecting a crosstalk signal may be reduced considerably by placing the electrode in the midline of the belly of the muscle. The double differential technique can eliminate the crosstalk in the EMG detected with surface EMG. Two differential signals detecting from three surface electrodes are fed into another differential amplifier. Thus we can filter out the EMG signal emanating from further distance muscles. Figure 2 presents the architecture of double differential technique.

The good measurement preparation can also reduce noise. For example before attaching the electrode on the skin, we treat the conductive glue to reduce skin impedance. Several noise sources can be attenuated by reducing the electrode-skin impedance through proper skin preparation[4;8].

2.3 Signal conditioning

No matter how we carefully prepare before measuring fEMG, EMG signal is still could contain the component of noise and error. So a signal-conditioning procedure is necessary. Figure 3 displays the EMG signal acquiring flow diagram. In the first stage, we attach or insert the electrode on the subject's skin, which is over the interesting muscle. The collected EMG signal is delivered through shield cable to the preamplifier. The preamplifier provides two functions. (1) The preamplifier adjusts the EMG signal amplitude to fit into the input voltage range of the analog-to-digital converter (ADC). (2) The high input impedance of amplifier could minimize the loading effects. Before encountering the ADC, the input signal is processed with the anti-aliasing filter to remove all frequencies above the Nyquist frequency. This is done to prevent the aliasing effect during sampling. ADC passes the analog EMG signal to digital computer. In the computer, we design the digital filters for advanced signal processing. The first band-stop filter reduces the 60Hz power line interference. The second band-pass filter is designed to obtain the required operational band (10Hz to 500 Hz). Eventually, the EMG passes through the full wave rectifier and low pass filter with 3Hz cutoff frequency to get the activation timing of muscles.

Although the shielding technique can remove the power line interference efficiency, this method is not always feasible in practical measurement. It is really necessary to reduce the interference by signal condition means. The Bandstop filters (i.e. notch filters) are usually used for eliminating the component of power line noise. Also, signal conditioning can also reduce motion artifact. Because the power spectrum of motion artifact is mostly below 20 Hz, a simple high pass filter could achieve this goal.

In spite of the filtering can reduce noise efficiently or how

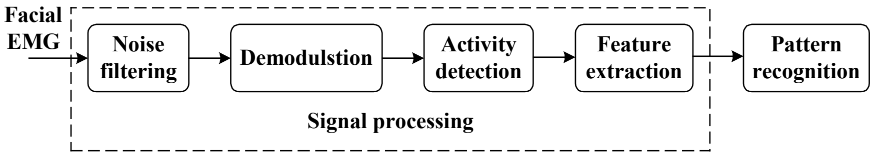

Figure 4. The block diagram of speech pattern recognition system.

easy to use, filtering will alter the spectral content and rotating the phase of recording EMG. For this reason the adaptive filter method have been proposed. The disturbances, which come from physiological signal, are defined intrinsic noise like ECG, EEG and breath. The biopotentials such as the EOG, EEG, ECG, EMG, are possible occurrence simultaneously and interfere with each other. For example, the measurement of fEMG may include the component of EOG, EEG, and ECG at the same time. Besides, the EMG coming from other muscles is also a kind of sources of noise. Above noise sources all could affect the facial EMG. For resolving the problem of signal overlap, many signal processing algorithms have been developed to eliminate the noise. Moretti et al. use ordinary least square (OLS) method, which is a representative regression method to correct the EOG artifacts in time domain[9]. Allison makes use of the standard threshold and integrated profile algorithm to filtering the ECG signal interference, when measuring the EMG [10].

Masticatory Function Evaluation

Masticatory motion is the main function of oral system. Through masticating and swallowing, the humans can acquire nutrition to maintain life. The quality of the mastication function would affect the eating capability and the absorption of the nutrient. Since the mastication is an important healthy and living factor for human, it is essential to precisely evaluate mastication function. Fortunately, the achievement of masticatory action relies on the coordination of facial muscles. We can evaluate the masticatory function from the muscle efficiency, the performance of mastication activity and the biting force. The muscle activity is the considering method in this section, because this factor is highly related to fEMG.

3.1 Measurement method and applications

Because the biting force can represent the activity of the mastication muscle, hence the measurement of biting force is often used to estimate the chewing function. We can access the biting force by biting meter, strain gauge, and the EMG amplitude. In the clinical studies of masticatory motion, the biting force is divided into two categories: (1). The functional biting force: (2). The static biting force. We can examine the activity of the masticatory muscle by measuring the EMG amplitude when chewing foods. But there still exist many factors that could lower the accuracy of the fEMG. The important factors include: (1). Age of the subject [11]. (2). Sex of the subject [12]. (3). The type of the skull: [13]. (4). The occlusion of the tooth [14].

Just as we have mentioned above, we have to shave the skin in the corresponding area and cleansing it with an alcohol-wetted swab before attaching the electrode on the skin. In order to find the correct electrode site, the subjects are asked to tightly bite the tooth. Then we can find the anterior temporalis muscle and masseter muscle by touching the corresponding anatomic site. The electrode pair is parallel with the direction of the muscle fiber, and the reference (grounding) electrode is put on the right ear lobe of the subject.

Gramling et al. have also accessed the masseter muscle contracting by measuring fEMG amplitude[15]. In the investigation of the temporomandibular disorders (TMD) patients, Ferrario used the disposable Ag/AgCl bipolar electrodes with a diameter of 10 mm and the inter-electrode distance of 21±1 mm[16]. The reference electrode was applied on the forehead. The EMG activity of the masseter and the temporalis anterior muscles are recorded during biting.

3.2 Conclusion and recommendation

Masticatory function evaluation can diagnose the disorder of oral system in the early stage. It can prevent tooth abrasion, periodontal injury and the overuse of oral muscle. Moreover, we can combine masticatory evaluation with the treatment, such as biofeedback. Through continuously monitor muscle activity and feedback to patients, we could improve the efficiency of therapy substantially.

Speech analysis and recognition

Facial EMG is now a well-established technique in studying human speech productions[1]. Current speech research in fEMG is devoted to anti-stuttering, disfluency-detecting and auxiliary in speech recognition. The fEMG is also a useful tool in speech production research and the speech therapy for the speech pathologist.

The auxiliary of facial muscle is an importnt part to complete speech production. Process of sound production includes the motion of oral muscle, the assistance of the tongue, and the vibration of the vocal cords. In the speech process, the respiratory, pronunciation and the sound resonance have to properly coordinate with each other. Any failure of the speech mechanism could cause dysphonia. For example, the sufferers of cerebral paralysis cause the abnormal muscle tension and the strong reflection. This situation seriously degrades the quality of communication.

4.1 Speech pattern recognition

The fEMG is also suitable for speech pattern recognition[17]. By attaching the surface electrodes on the interesting muscle we can pick up the raw fEMG. Then the raw EMG data can filter out the artifact and noise by using well-designed filters. We need to find the muscle activity interval and to acquire the EMG feature in each speech event. Eventually, the neural network can classify the EMG feature of different speech pattern. Figure 4 shows the block diagram of a speech pattern recognition system.

Watson have presented two examples to illustrate the need and the potential of investigating speech production at multiple representational levels[18], such investigations provide insights into normal control of the speech process. Grandori et al. proposed a first-approximation functional model to organize and to assess the collected data.[19]. During different phonatory tasks, simultaneous measurements of oromandibular EMG signals and speech seem to provide a tool that can separate perceptual and mental processes from peripheral phonatory and articulatory processes. This model can improve the accuracy speech recognition.

4.2 conclusion and recommendation

When we study the production of human speech, fEMG provides an effectively evaluative tool. However, the idea of fEMG speech recognition is still in the research stage. In order to make these systems become a practical device, we have to augment the speech database and improve the off-line algorithm meeting the real-time requirement. We also need to find much more fEMG features to classify a large number of speech patterns. Every subject all has his own individual speaking style; this means the same speech pattern could cause different EMG feature. This may degrade the system performance. For solving this problem, we must explore optimal pronunciation style and train the subjects adopting identical speech manner. Finally, we shall endeavor to make the user interfaces more powerful and friendly.

Emotional expression observation

Facial expression is a common language for all humans. We can observe small variety of facial expression from other people and then realize their feeling and ideas. The coordination of facial muscles performs every kind of facial expression. Therefore, we can measure the fEMG, responding the facial emotion, to observe the phenomena of physiology and psychology. In addition, the fatigue is also kinds of human emotion characteristics. The fatigue degree can be detected by the degradation of the facial muscle activity[20]. In this section we discuss the fEMG applied to the emotion evaluation.

5.1 Measurement method and research result

The fEMG can detect heartfelt of human, such as hearty smiles or unwilling smiles. Surakka et al. measured the fEMG on orbicularis oculi and zygomaticus muscle regions motion and ask the subject to fill the questionnaire in the same time[21]. This implies that fEMG can detect whether the smile is coming from heart or just the motion of surface muscle. In order to analyze the muscle affected by emotion, Sloan et al. divided the subjects into two groups, the dysphoric and non-dysphoric persons[22]. The subjects are asked to look at the image with different feeling and a clinician recorded the fEMG responses. The sensors were attached on the left side of the face over the zygomatic and the corrugator supercilii muscle regions. The experimental results indicated that dysphoric persons have impaired interpersonal reactivity that is specific to happy facial displays.

Hu et al. also conducted two experiments to observe the fEMG activity for different tastes effect[23]. Subjects described the hedonic sense and fEMG activities in the levator labii superioris/alaeque nasi region were recorded in each experiment. The experiments showed that fEMG activity could be used as a palatability indicator.

De Jong et al picked the levator, corrugator, and zygomatic muscle activity as evaluative index of fatigue[24]. Veldhuizen et al. recorded the facial corrugator superciliiand EMG activity in the frontalis muscles to estimate the degree of fatigue[20]. EMG activity was recorded by surface electrodes which are located on the corrugator and frontalis muscles. The reference electrode is placed on the middle of the forehead, and the EMG activity was recorded during a simulated workday.

The auditory stimuli also affect the facial muscles. This phenomenon might result from the emotion reaction of hearing stimulating. Jancke et al. evaluated the hearing stimuli in subjects by fEMG[25]. The experiment includes hearing different degree of stimulus and the EMG recording on five facial muscles. The result indicates that the upper face (the auxiliaries of the forehead) EMG signal can respond the strong reaction of auditory stimuli.

5.2 Summary and recommendation

By measuring fEMG, the researchers could quantify the emotion data. This method may avoid the subjective errors and save the time in recording the facial motion patterns. The fatigue might affect deliberating process and degrade the ability of judgment. Furthermore, the fatigue will not only reduce the working efficiency but also obscure the subject vision. The fatigues comprise physiological labor and psychological stress. We can detect the physiological fatigue by directly observing the EMG characteristic variation. However, quantifying the psychological fatigue is still very difficult. The facial expression has great potential in quantification of the psychological fatigue. This method can also provide a useful tool to diagnose the increasingly serious fatigue diseases, such as the death from overwork.

Conclusion

The application of fEMG can help the speechless human communicating with other people. By recording the fEMG signal, we can analyze the voice signal and realize the mechanism of voice production. This fEMG technique may be applied to detect and to diagnose the stroke patients in the early stage or to estimate the masticatory function. Facial EMG can recognize the facial expression, such as pleasure, anger, sorrow and fatigue. In addition to the previous applications, fEMG can also be applied to other fields. For example, we can create the face computer animation model by measuring the movement between skull and facial muscle. The fEMG is also used to evaluate the anti-G straining maneuver (AGSM) performance when combat jet pilot suffers rapid onset high-sustained G force. This method can build an objective evaluation model and improve the training procedure of AGSM.

In the future, it is essential to develop the technique of the sensor and measurement suitable for applying in different facial locations. This can improve accuracy and increase the convenience in the measurement. If we want to promote the fEMG technique to commercial product, many problems still exist. Firstly, when recording the fEMG, we hope to decrease the number of electrode the attaching on the face, so that we can make the design of system easier and reduce developing cost. Furthermore, the existence of the electrodes will affect the movement of facial muscle and decrease the validity of measurement. Eventually, the facial electrode may impair the appearance of subjects and reduce acceptance for fEMG product. For design of facial sensor, it is a critical task to find the position of interesting facial muscles and fix the electrodes on the face without disturbing the facial movement.

The application of facial EMG has great potential in biomedical engineering. It is very worth for researchers of biomedical community investing time and effort in this field. We hope this article can provide some guidelines to the people who study the facial EMG.

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