Wearable Electronics for Surface and Needle Electromyography Measurements

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Abstract. Because the electromyography (EMG) signal can reflect the potential of muscle contraction controlled by neural activities, it has aroused great interest from researchers. As a result, a number of studies have been conducted around EMG. EMG-based wearable electronics are used not only in the diagnosis of neurogenic or myogenic diseases but also in sports science, rehabilitation, augmented reality, and virtual reality. This article briefly introduces the development history and background of EMG technology, then focuses on the classification of EMG and its technical mechanisms and reviews representative EMG-based wearable electronics. Finally, the challenges and development trends of EMG-based wearable electronics are also discussed. Developing devices with high specificity, adaptability, and robustness remains challenging. It has become a trend to optimize EMG signals' classification, characterization and noise cancellation algorithms for future study by combining multiple technical means. Because of the various applications of wearable electronic devices based on EMG measurements, it will have promising prospects in many fields.

Keywords: Wearable Electronics, Electromyography, Measurement

1. Introduction

A biosignal refers to any signal from human bodies that can be continually measured and monitored [1]. Biological signals can reflect the state of life activities of human beings because they derive from different parts of the body, such as skin, eyes, heart, muscles and stuff like that. Thus, the collection and processing of biological signals are one of the essential parts of biological science research. It can be divided into two parts: bioelectrical signal and non-bioelectrical signal. Bioelectrical signals contain electroencephalogram, electrocardiogram, electrooculogram, electroretinogram, electromyogram, etc. Non-bioelectrical signals comprise mechanical, chemical, optical, and acoustic signals.

Electromyography, as one of the crucial diagnosis techniques, was first introduced by Etienne Marey in 1890, who finished the first real recording of muscle contraction electrical activity. Before that, scientists in the 17 to 18th, such as Jan Swammerdam, and Luigi Galvani, conducted experiments to verify that muscle contraction to electrical stimulation. Then in 1838, Carlo Matteucci invented the galvanometer to demonstrate the close relationship between bioelectricity and muscular contraction and manifested the occurrence of action potential in frog's muscles. And in 1850, Guillaume Duchenne implemented electrical stimulation to intact skeletal muscles with external handheld electrodes, finding that the electrical stimulation accompanies the changes in facial expressions on different parts of the face [2].

EMG signal is used for measuring electrical currents produced by the contraction of muscle to show neuromuscular activities. And the nervous system invariably controls muscle activity (contraction/relaxation). Therefore, to a certain extent, EMG signals can reflect the state of neuromuscular activity. Utilizing powerful and advanced EMG signal detection tools is a significant requirement because of the potential applications in clinical diagnosis and biomedical areas [3].

This article provides a brief overview of the development history and background of EMG technology, then focuses on the classification of EMG and its technical mechanisms, concludes with a review of representative EMG-based wearable electronics. Finally, the challenges and trends in the development of EMG-based wearable electronics are discussed.

2. Wearable electronics for EMG measurement

With the recent years' development of technology, the application of wearable electronics for electromyography measurement has emerged in an endless stream. There are two main methods to acquire EMG signals, one is surface electromyography (sEMG) and the other is needle electromyography (dEMG) [4].

sEMG is the noninvasive technique of recording the electrical signals produced by the contraction of the surface muscle. At least two electrodes will be adhered to the surface of the target muscle to record the slight potential difference from the muscle contraction on the surface of skin. This weak potential signal will be eligible for processing after being amplified and converted.

dEMG is an invasive technique by means of a needle electrode inserted in the muscle., which can record and evaluate the electrical signals generated from single muscle fibers of motor units during rest and voluntary contraction. dEMG requires the placement of a needle electrode into a muscle., capturing and amplifying the electrical signals generated by resting or contracting muscle fibers, and elucidating the signals to identify the function of the muscle fibers and motor units [5].

2.1. Applications of surface EMG measurement

Jebelli et al. [6] conducted research that determined the viability of evaluating workers' muscle fatigue by analyzing their physical stress at construction projects through the wearable EMG. In the experiment, they measure the electrical activity in eight healthy subjects while using their upper limbs, such as the biceps and shoulder muscles, to carry out two tasks with varying levels of fatigue. Simultaneously, the wearable EMG device records EMG signals from both the biceps and shoulder muscles of the subjects. Furthermore, subjects are required to rate their fatigue levels every 15 seconds, focusing on completing the two tasks above. Before analyzing the acquired signals, different filtering methods, such as a notched filter with a 60 Hz cutoff frequency used to filter out external electromagnetic sources, a Hampel filter for removing abnormal signal value, and a bandpass filter combined with low cutoff frequency and high cutoff frequency for reducing exterior signal artifacts, are used to eliminate various noises from sources other than muscular activity. The mean absolute value, root mean square, mean frequency, and intermediate frequency of the filtered EMG signals are chosen as indicators of the potential of EMG signals for the measurement of workers' muscle fatigue. And the Borg rate of perceived exertion (RPE) scale, which is a common and reliable way to assess perceived muscle exertion, acts as the baseline for measuring the level of muscle fatigue in subjects. In this state, EMG signals are divided into Low Fatigue Level (RPE scale between 0 and 2), Moderate Fatigue Level (RPE scale between 3 and 4), High Fatigue Level (RPE scale between 5 and 7), and Extremely High Fatigue Level (RPE scale between 8 and 10). As a result, EMG-based metric values for the biceps and shoulder muscles are calculated while subjects performing the experimental task at different fatigue levels are shown. The results show that higher levels of muscular fatigue display a higher mean absolute value and root mean square of the signal but a lower mean frequency and median frequency of the signal. These findings have the potential to improve construction workers' productivity, safety, and well-being by creating an automatic and mountainous framework that measures muscle fatigue based on EMG signals.

Conradsen et al. conducted research for modified version detection of generalized tonic-clonic (GTC) seizures based on a surface EMG recording device [7]. This novel wearable sEMG device is able to set the alarm for specific detection algorithms during seizures besides standard EMG data recording. In addition, this wearable device, embedded in a wireless detection device to avoid artifacts of wirepulls, is expected to detect most GTC seizures and have more favorable results. The study includes five patients (annotated from D207 to D211) with GTC seizures for diagnostic reasons. Five subjects stay in the hospital for two to five days, which supplies numerous data. The wireless sEMG device is located on the left or right tibial muscle (as shown in Figure 1), which depends on where each subject typically expressed most during seizures. And the alarm system in sEMG is hidden and only known by researchers. Finally, the beginning and end times will be recorded by physicians with the help of the gold standard (video and electron-cephalography signals). Compared with the previous

algorithm design, they make some filter design and detection threshold changes, which is more suitable for sEMG signals collected from wireless sEMG devices. In results, the device manifests a 100% sensitivity and no false alarms in patients D208-D210, except for patient D211(the missing data for D207 due to some recording problems). The reason that three of the seizure in patient D211 can't be caught by the algorithm is that these seizures are divergent from typical GTC seizures. Regular GTC seizures are usually relatively average; by contrast, these three contain more interchanging but shorter tonic and clonic phases. Therefore, these are missed by the algorithm. Ignorance of outliers from D211, this wearable sEMG device for detecting GTC seizures has 100% sensitivity.



Figure 1. The wireless sEMG device is located on the tibial muscle [7].

Leone et al. carry out research about a real-time and low-invasive device for evaluation of the risk of fall based on sEMG [8]. In this research, sEMG signals are supposed to acquire from two lower limb tibialis and gastrocnemius muscle groups, which play an essential role in predicting fall [9]. Hence, this wearable EMG device is placed on subjects, as shown in Figure 2A. In the beginning, to acquire enough data for cultivating and testing the algorithm of fall risk evaluation, seven subjects are required to be involved in this experimental simulation under three specific conditions: a) Daily life activities; b) walking and sedentary behaviors in normal condition; c) unstable situation (typical fall occurrence), simulated by tilting platform (as is shown in Figure 2B) equipped with the inertial measurement unit Xsens MTi10 device as shown in Figure 2C. To remove artifacts, the raw sEMG signals will be pre-processed by a bandpass filter with a finite impulse response of 12th order and cut frequencies ranging from 20 to 450 Hz.

What's more, the subjects wearing the devices need to keep in a still position for 5 seconds to gain a baseline of signals. And then, the EMG signals will be performed a feature extraction and classification, taking the muscle Co-contraction Indices (CCI) and Integrated EMG (IEMG) as time-frequency domain analysis methods. In results, it demonstrates that the low threshold for CCI parameters detects all simulation instability events. However, several false alarms occur. On the other hand, with a high threshold value, false alarms decrease, but several true alarms in many imbalanced situations are missed. Hence, the median threshold is selected as a system archetype to balance the experimental results. Moreover, when combining IEMG and CCI parameters are involved in system design, higher specificity while the same sensitivity is produced.

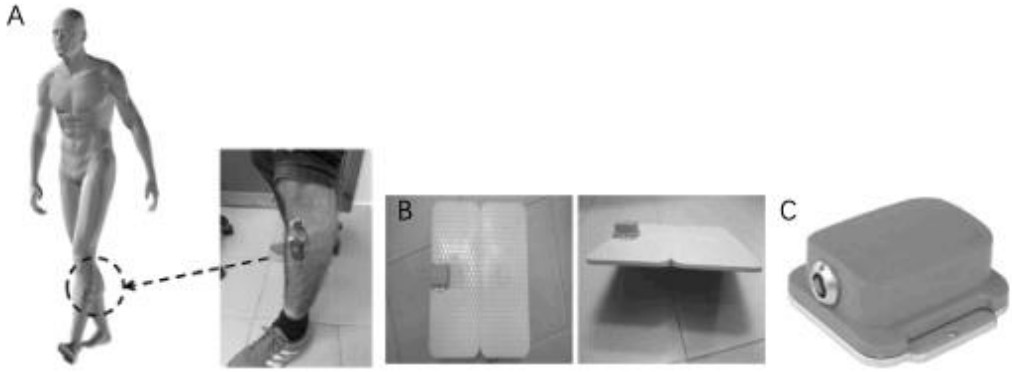


Figure 2. (A)The location of EMG probes during the acquisition; (B) Tilting platform to perform unbalanced trials; (C) Device (XSENS MTI10) for the angle inclination and speed assessment of the tilting platform [8].

2.2. Applications of needle EMG measurement

Satti et al. [10] developed research to determine the effectiveness of driver drowsiness detection through the measurement of muscle activity in relation to steering wheel grip. In the experiment, as is shown in Figure 3, EMG signals are collected from the muscle related to the steering wheel grip through microneedle electrode (MNE). Then, the feasibility of acquiring reliable EMG signals from MNE tech has been justified by comparing them with signals gained from Ag/AgCl electrodes. Time and frequency domain analysis is implemented to examine the time and frequency response of the resulting EMG signal in the research. And the short-time Fourier transform and spectrogram are used to recognize the frequency distribution of the resulting signal over time. Simultaneously, to detect and alert the driver in real-time, a novel amplitude shift-based driver drowsiness detection algorithm is introduced. Firstly, EMG signals obtained from MNE during driving will be amplified and filtered to remove exterior interference. Then EMG signals become digitalized by the microcontroller and are carried out for rectification, converting all negative signal values to positive and taking the average of the sum values per second. After calculating the average, the EMG signal value acts as a single value in the selected time window and serves as the threshold value. If the calculated average value exceeds the threshold in the allotted time, the driver will be alarmed not to drive drowsily.

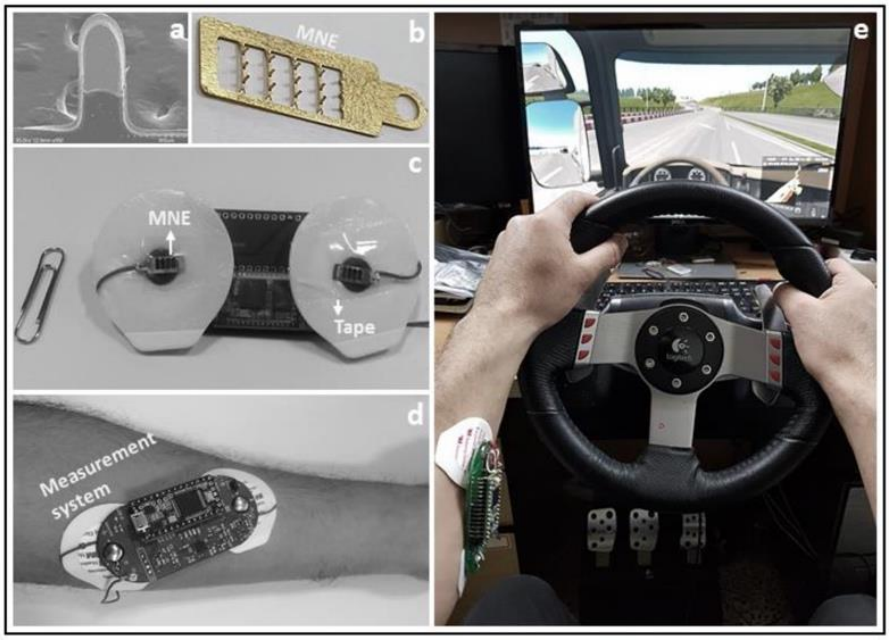


Figure 3. (A) SEM image of single microneedle; (B) MNE; (C) MNE contacted with skin by sticking tape; (D)MNE Measurement system; (E)Simulation driving system [10].

The findings show that participants' drowsiness increased during driving tasks, while muscle activity involved in steering wheel grip decreased over time. Thus, the results manifest that it is feasible to detect and warn drowsy drivers based on muscle activity.

3. Discussion

In the review of past representative wearable electronics EMG applications, tremendous developments have been made. However, shortcomings still need to be addressed. In the first application, Jebelli et al. have shown the feasibility of studying workers' physical stress to analyze their muscle fatigue on construction sites through the wearable EMG. However, limited subjects are involved in the research. More research on different muscle groups should be conducted to support the plan that improves worker productivity, safety, and well-being by developing an EMG-based framework for analyzing muscle fatigue.

In the second study, Conradsen et al. implemented research for modified version detection of GTC seizures based on a surface EMG recording device. Although this device shows 100% sensitivity except missed one value and one outlier, more works have still existed be done, such as improving the detection of GTC seizures detection algorithm and testing wearable sEMG device with signals from biceps sEMG (Because in researchers' unreported studies, biceps sEMG signals demonstrated better data than tibial muscle).

In the third study, Leone et al. researched real-time sEMG device for predicting fall, finding that the combination of muscle Co-contraction Indices and Integrated EMG can increase the specificity of the device system, compared with single time-frequency domain analysis methods, but the sensitivity remains the same. Thus, it is expected that more sensors and sophisticated threshold value calculation will be introduced to improve the robustness and performance of this EMG-based system for pre-impact fall detection to assess fall risk better.

In the fourth study, also the only one based on dEMG, Satti et al. demonstrated the effectiveness of determining driver drowsiness by measuring muscle activity in relation to steering wheel grip. Nevertheless, since EMG signals vary from person to person, the proposed algorithm's dependability must be rigorously tested in more subjects and with different experimental designs. Other physiological signals, such as an electroencephalogram or an electrooculogram, could be combined with EMG in future studies to create a more reliable and effective driver drowsiness detection system. The advantages of the EMG technique include high sensitivities, continuous detection, detecting action potential produced by neuromuscular activities, diagnosing neurogenic or myogenic diseases, etc. However, there are several disadvantages or limitations to the EMG technique. It only gives information about muscle fibers and motor units but fails to supply some definitive information on the disease's etiology [5].

The dEMG, which needs needle electrode penetration into the skin, can assess myoelectric changes in the deep muscles and be able to measure the potential changes of a single muscle fiber. But it fails to measure myoelectric changes during motion and could have some latent risks, such as pain, bleeding, needle stick injuries [11], contaminating blood [4], and even pneumothorax seriously as well.

As for the sEMG, as a non-invasive and easy-to-handle technique, it can measure myoelectric changes in the whole muscle during motion. Nevertheless, signals generated from sEMG are complicated, caused by the external environment, such as the resistance of the skin, muscle activities, etc. EMG technologies with different principles depend on wearable electronic devices with different purposes.

4. Conclusions

This review highlights the characteristics of the EMG technique and its applications in wearable electronics. The advantages of high sensitivity, continuous detection, the ability to detect action

potentials generated by neuromuscular activity, and the feasibility of diagnosis of neurogenic or myogenic diseases have also attracted the interest of many researchers. Recently, researchers have improved worker productivity, safety, and well-being by creating an EMG-based framework for analyzing muscle fatigue. And research about devices for EMG-based detection of GTC has progressed. At the same time, combined with a variety of time-frequency domain analysis methods, the effectiveness of the equipment for predicting falls is improved. What's more, it can also detect and alarm drivers of drowsiness by measuring muscle activity in relation to the steering wheel grip. As various chips and sensors are developed, wearable smart devices based on EMG measurement have progressed from concept to commercialization and are constantly promoting their growth.

However, some challenges are still left over for practical applications of wearable electronics for EMG. On the one hand, nEMG-based wearable electronics are limited to measuring myoelectric changes during exercise and give rise to health risks. On the other hand, the accuracy of sEMG-based wearable electronics is easily susceptible to the external environment.

For future research, some work remains to be done. For example, further expanding the research subjects and enhancing its practicality, combining deep learning and machine learning into EMG signals detection to optimize the classification, characterization and noise cancellation algorithm of EMG signals. At the same time, multi-mode combining EMG with electroencephalogram, electrocardiogram, electrooculogram, electroretinogram, etc. has also become a demand. Moreover, wearable electronics based on EMG are used not only in diagnosis associated with neurogenic or myogenic diseases but also in sports science, rehabilitation, augmented reality, and virtual reality.

In the end, wearable electronics for electromyography measurement own a promising future in many fields of our everyday life.

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