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Original Article

Low-cost 2ch EMG biofeedback device using a stereo microphone port

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ABSTRACT
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Objectives: EMG-BF therapy in rehabilitation clinics requires the installation of an expensive electromyographic biofeedback (EMG-BF) device. However, many medical institutions find it difficult to purchase the device because of the high cost, and so the availability of EMG-BF therapy is limited. This study aimed to develop a low-cost and simply designed EMG-BF device using a stereo microphone port. The device can be easily fabricated even by people without knowledge and skills related to electronics.
Methods: The proposed device comprises an EMG amplifier, personal computer (PC) with a microphone port, electrodes, and their cables. The device is designed to be as simple as possible and with minimum components so that medical staff can obtain the required components and easily fabricate the device themselves.
Results: The amplifier consists of approximately 20 easily obtained components, and costs approximately 1,600 yen in total. This device can display the voluntary EMG of the extensor carpi radialis and flexor carpi ulnaris muscles in normal adults on a PC screen, enabling the amount of muscle contraction to be identified.
Conclusion: This device may help increase the use of EMG-BF therapy, and thus improve the quality of rehabilitation in clinics and homes.

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Keywords: EMG monitor, EMG biofeedback therapy, motor learning, neurorehabilitation

Introduction

Since Marinacci et al. [1] used electromyographic biofeedback (EMG-BF) for neuromuscular re-education therapy, it has become an important treatment method for motor learning in rehabilitation medicine. Though EMG-BF therapy is commonly practiced in the U.S. and Europe, it has yet to find wide acceptance in Japan [2] and sufficient clinical studies have not been conducted. The proposed therapy aims to improve performance by displaying the levels of muscle contraction to patients. This is done by converting the levels into sensory signals, such as light and sound, and helping the patients control muscle contractions based on the information obtained. This therapy can be broadly classified based on whether it is aimed at facilitation or inhibition of muscle contractions, and is considered to be a suitable treatment for a wide range of symptoms such as writers' cramp and facial paralysis, as well as for swallowing training [3]. Additionally, multi-channel EMG-BF [4, 5] has been performed for the contraction and relaxation training of each muscle through the synchronization of activities of several muscles, such as agonist and antagonist muscles, and the effectiveness of the therapy has been confirmed.

EMG-BF therapy requires an EMG amplifier and a display device to aid visual or auditory perception. Although these EMG-BF devices are manufactured for and sold to the general public and medical professionals, their prices range from several thousand up to one million yen; the high cost makes it difficult for medical institutions to purchase them. In 2008, the Japanese Association of Rehabilitation Medicine [6] conducted a survey on related devices among 253 rehabilitation institutions nationwide. It revealed that these institutions own 33% of the EMG-BF devices; this figure is almost identical to that of devices such as Hubbard tanks which are rarely used today. On the other hand, the estimated percentage of those desiring to purchase EMG-BF devices was the highest among the 26 exercise therapy devices surveyed for this study. This indicates that there is a high demand for EMG-BF devices at clinics where the devices could be installed if the budget permits [2]. Hence, the high price of EMG-BF devices is believed to be restricting the extensive use of EMG-BF therapy. We consider that the use of EMG-BF therapy could be increased and hence the quality of rehabilitation medicine could be improved if therapists and physicians could easily fabricate EMG-BF devices at low cost themselves, similar to the assembly of patients' self-help devices. Moreover, if these devices could be fabricated by the patient's family members, it could lead to widespread use of higher quality voluntary practice at home.

This study aimed to develop a low-cost 2ch EMG-BF device for which medical professionals, who lack sufficient knowledge and skills related to electronics, can procure the necessary components and build themselves.

Methods

1. Device overview

Figure 1 shows the structure of the proposed device. The device comprises the following: an EMG amplifier (usually enclosed by materials such as heat-shrink tubing; however, in the figure, the materials are removed to demonstrate that the amplifier has simple circuits); electrodes; electrode cables; and a personal computer (PC) with a microphone port. EMG waveforms and their power spectrum are displayed on the PC screen using audio waveform display software. The total cost of the EMG amplifier components is approximately 1,600 yen. Electrode cables cost about 800 yen per channel and electrodes (consumables) cost about 1,300 yen per channel.

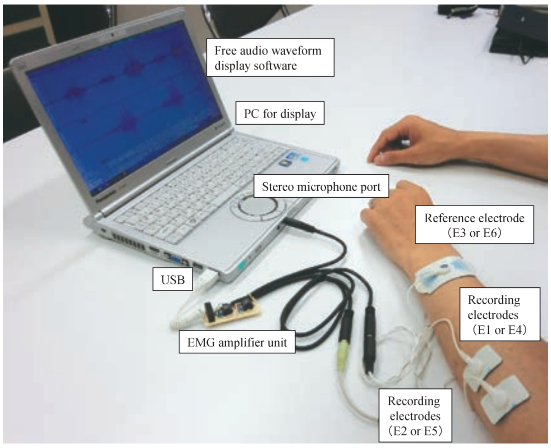

Figure 1. Structure of the device.
The proposed device comprises the EMG amplifier unit, recording and reference electrodes, electrode cables, and a PC with a stereo microphone port. The PC screen displays the EMG waveforms, their power spectrum, and a meter to measure muscle contraction levels using audio waveform display software.

2. EMG amplifier circuit

Figure 2 shows the EMG amplifier unit circuit and Table 1 lists the components. Medical staff need to be able to build this EMG amplifier unit on their own. Instrumentation amplifiers (IC1, IC2: LT1167 in Fig. 2) were used, one for each channel, in the EMG amplifier. We placed 1 kΩ resistors (R1 and R3 in Fig. 2) in each amplifier for adjusting the amplification factor and amplified the power by approximately 50.4 times. In addition, to prevent saturation caused by the amplification of the DC bias voltages owing to unbalanced contact impedances, we installed two pairs of capacitors (C1 and C2, C4 and C5 in Fig. 2) of 1 μF in parallel. These capacitors are aligned with the adjusting resistor in series and produce high-pass filter properties (lower cutoff frequency: 79.6 Hz). This allowed us to keep the direct current components unchanged. For EMG testing conducted in a shielded room, the lower cutoff frequency is typically set at 20 Hz at the time of EMG detection. However, to enable the device to be used in a training room for EMG-BF therapy and to eliminate the noise caused by commercial frequencies (e.g. 50 or 60 Hz) and the wandering baseline during movements, we set a relatively higher cutoff frequency of 80 Hz. Furthermore, we placed passive CR low-pass filters (R2, C3; R4, C6 in Fig. 2: upper cutoff frequency: 1,940.9 Hz) at the output section of the amplifier to reduce high-frequency noise.

For convenience, a USB type-A port was used to supply power to the instrumentation amplifiers from the USB port of the PC. A standalone DC-DC converter (IC3: MAU109 in Fig. 2) supplied power to each instrumentation amplifier after the 5 V of power from the USB port had been boosted by an extra ±15 V. The standalone DC-DC converter was used to prevent internal short circuits when the ground levels for the microphone and USB ports became different upon connecting a device to the USB port of the PC.

The input port of the amplifier was connected to the 3.5φ stereo jack to which the electrode cables were connected. The output port of the amplifier was connected to the 3.5φ stereo plug that was to be connected to the microphone port.

Additionally, it was confirmed that manufacturing the proposed device would not infringe any patents.

3. Screen display

To display the EMG waveforms captured through the microphone port on the PC screen, free audio waveform display software for Windows was downloaded and installed on the PC. A handy oscilloscope [7] (OS: Windows 8/7/Me/XP) was used as PC screen display software in this study. If a

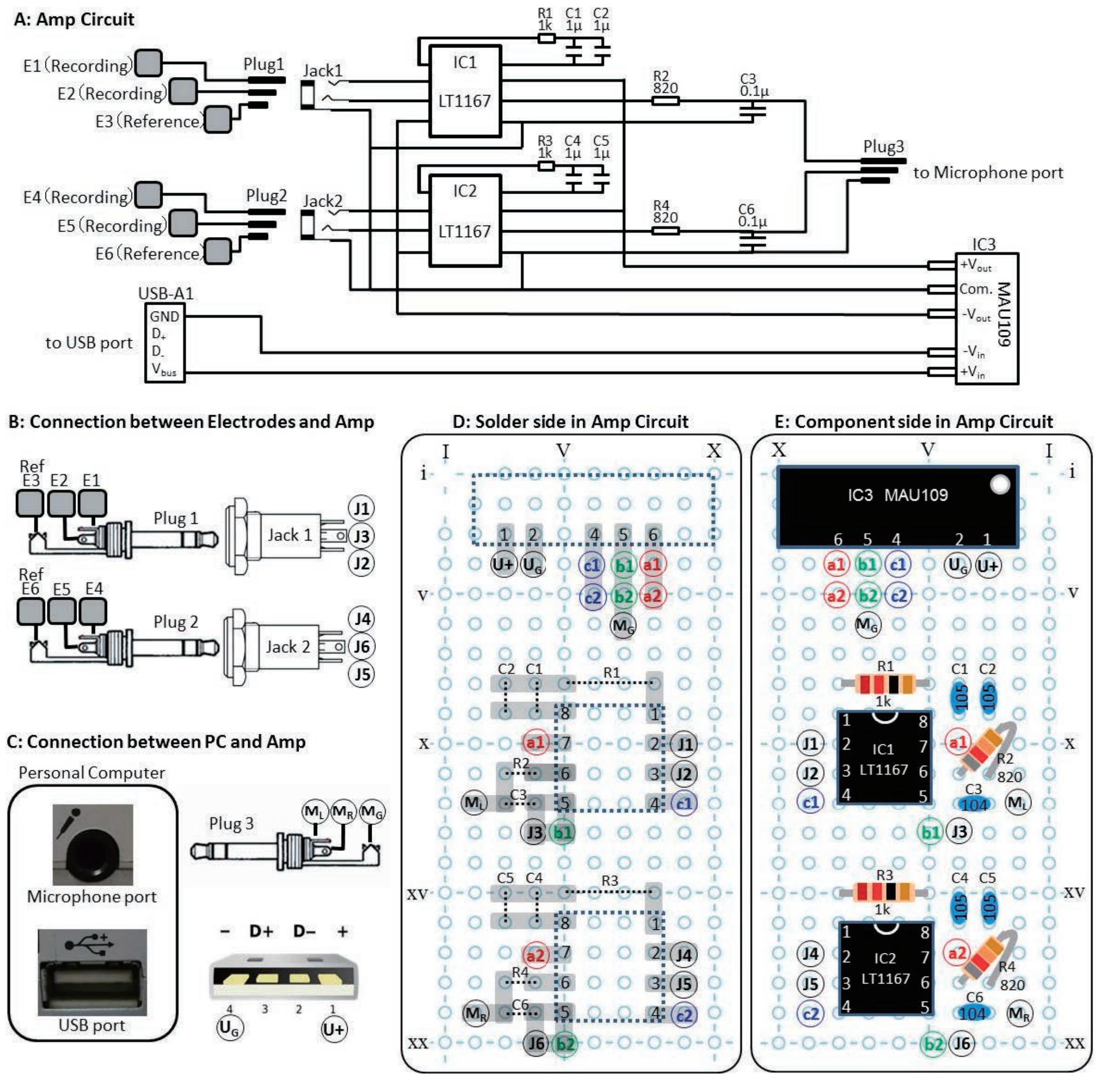

Figure 2. EMG amplifier circuit.
A: EMG amplifier circuit diagram. R1−R4 and the numerical values denote the resistances and resistance values (Ω), respectively. C1−C6 and the numerical values indicate the ceramic capacitors and capacitance (F), respectively. B: Reference electrode (the ground wire) and recording electrodes (E1−E6) are connected to the circuit with a plug and jack used for the headphones. Each electrode corresponds to J1−J6 on jack 1 and jack 2. C: Outputs from the EMG amplifier are transferred to the PC through the microphone port. Simultaneously, 5 V is supplied to the EMG amplifier through the USB port. D and E: Solder side on the universal board (D) and assembly drawing (E). Roman numerals indicate line numbers (in lowercase) and row numbers (in uppercase) on the board, and the Arabic numerals written on IC1-3 denote pin numbers for the ICs. The ones with the same encircled symbol will be connected with a lead or cable. The lowercase letters denote the connected sections in the circuit, and the uppercase letters denote the sections connected with plugs and jacks. The sections highlighted in gray on the solder side will be connected using soldering. In addition, measurements can be performed by placing the reference electrode on either E3 or E6.

Macintosh computer is used instead of a PC, screen display software that is compatible with the Macintosh operating system is required.

4. Operation verification test

Using the assembled device, the authors served as the test subjects and verified the operation of the device. A total of four electrodes (two pairs) to detect EMG signals were placed, one pair on the muscle bellies of the extensor carpi radialis (the extensor digitorum muscle) and one pair on the flexor carpi ulnaris muscles in the left forearm of a healthy adult male. Separately, one reference electrode was attached to the dorsal wrist joint. Then, the subject repeatedly performed palmar flexion and dorsiflexion of the wrist joint, as well as extension movements of the fingers,

Table 1. Parts and price list of 2ch EMG amplifier.

Schematic symbol		Part name	Model, Type,Number, etc.	Prices for reference	Subtotal
Board		Universal Board	×1	60yen/pc.	Amplifier unit about 1,600 yen
Power supply circuit	IC3	DCDC converter	MAU109×1	370yen/pc.	
	USB-A1	USB code	×1	105yen/pc.	
Microphone port	Plug3	3.5φ stereo plug	×1	50yen/pc.	
EMG amplifier circuit	R1-4	Carbon composition resistor	1kΩ×2, 820W×2	2yen/pc.	
	C1-6	Multilayer ceramic capacitor	1μF×4, 0.1μF×2	15yen/pc.	
	IC1-2	Instrumentation amplifier	LT1167×2	400yen/pc.	
	Jack1-2	3.5φstereo jack	×2	60yen/pc.	
Electrode	E1-E6	2 set of electrodes	HV-3DPAD×1	1,320yen/set	Electrode unit about 3,600 yen
Electrode code	Plug1-2	Electrode cord	HV-CODE-A×3	735yen/pc.	
		3.5φ stereo plug	×2	50yen/pc.	

Breakdown of EMG amplifier unit: Common part such as power supply: about 600 yen, Amplifier: about 500 yen/ch.

approximately once every second. We used Omron's adhesive electrode, which is available at general consumer electronics retailers, as a low-frequency therapy device (HV-3DPAD) by dividing it into three pieces. The recording electrode was trimmed to dimensions of approximately 30 mm × 20 mm. The EMG waveforms displayed on the PC screen were captured during repeated palmar flexion and dorsiflexion via the assembled device and stored as an image.

Panasonic's CF-SX-1 installed with Windows 7 (operating system) was used as the PC for screen display purposes.

Results

Figures 3 and 4 show the EMG waveforms displayed on the PC screen. Figure 3 depicts the EMG waveforms at the time of palmar flexion and dorsiflexion of the wrist joint. The upper and lower sections show the EMG waveforms for the extensor carpi radialis and flexor carpi ulnaris muscles, respectively. Figure 4 depicts the EMG waveforms for repeated extension movements of the fingers. The upper and lower sections show the EMG waveforms and their power spectrum, respectively. The time scale for the EMG waveforms in both figures was adjusted to 500 ms/div. The amplitude scale can be adjusted iteratively by using the bar located on the right side, and it was adjusted to approximately 10 mV/div for the measurements performed in this study for the sake of visual clarity.

These settings helped display a low noise level and excellent EMG waveforms, which permitted satisfactory visual perception of the amount of muscle contractions.

On Windows 7, we clicked "Control Panel," "Hardware and Sound," "Sound," "Recording," and "Microphone" in sequence. After clicking and opening the "Properties" for the microphone, we clicked the "Listen" tab. Next, we checked the "Listen to this device" option and then clicked "OK." Subsequently, we were able to confirm the myoelectric sound, which corresponds to the myoelectric volume, on connecting a speaker or headphones to the audio output port.

Discussion

The proposed EMG-BF device was fabricated by designing an EMG amplifier with the simplest possible circuits and by using the minimum number of necessary components. Two-channel EMG waveforms were input from the PC stereo microphone port, which is readily available to the general public, and then displayed on the screen. The components used as primary integrated circuits for the EMG amplifier comprised two items, namely, instrumentation amplifiers and an isolated DC-DC converter. The total number of components is approximately 20 including other minor components such as resistors, capacitors, and a USB port. Additionally, because these components can be obtained easily, we believe that medical professionals and ordinary people, without a detailed knowledge and skills related to electronics, can purchase the components and build the device. This would allow several EMG-BF devices to be

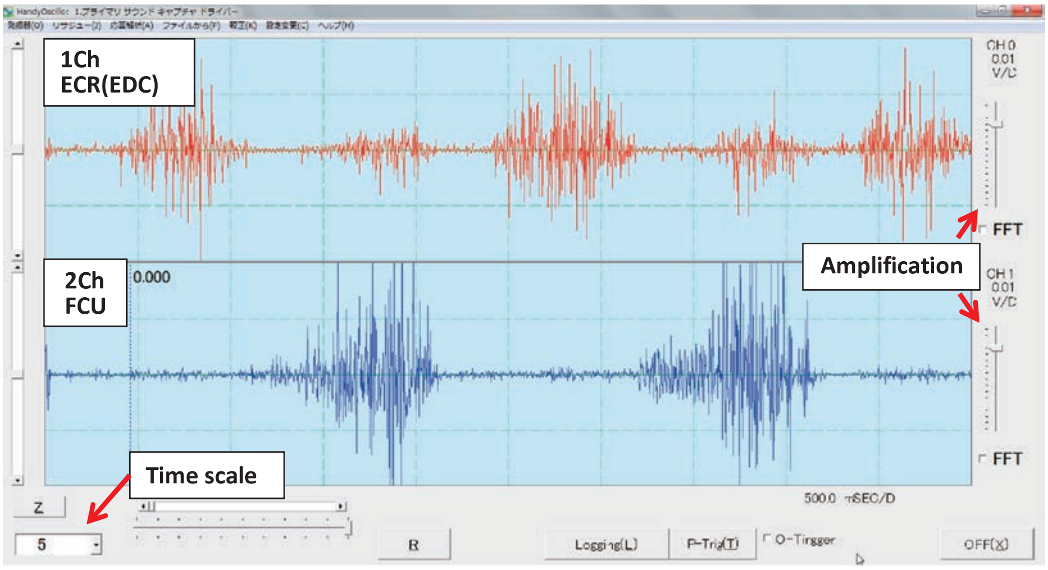

Figure 3. EMG waveforms displayed on the PC screen (2ch display).
EMG waveforms were captured during the palmar flexion and dorsiflexion of the wrist joint. The upper and lower sections show the EMG waveforms for the extensor carpi radialis and flexor carpi ulnaris muscles, respectively.

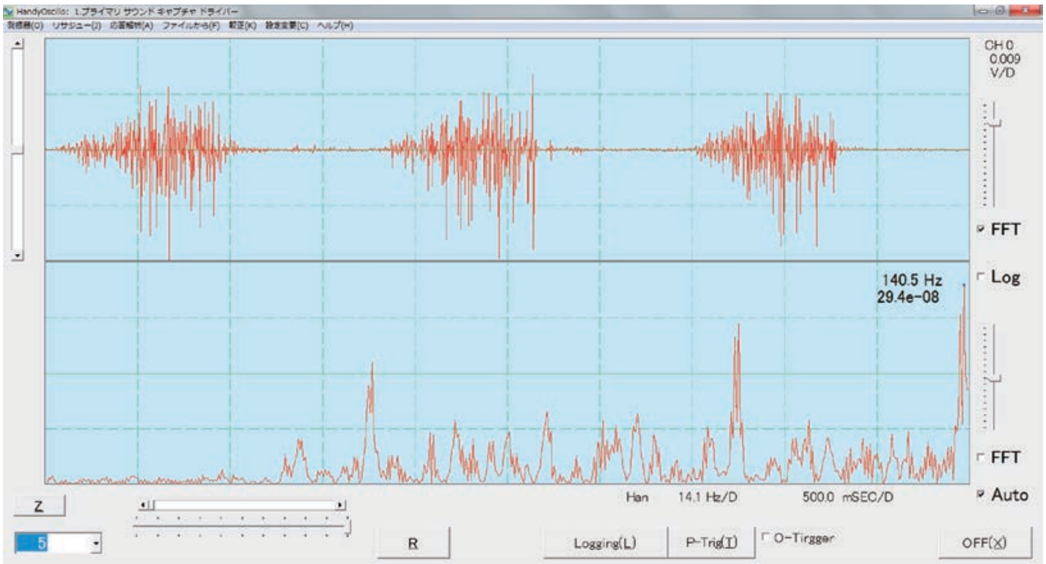

Figure 4. EMG waveforms displayed on the PC screen and their frequency spectrum.
EMG waveforms were captured during repeated extension movements of the fingers. The upper and lower sections show the EMG waveforms and their power spectrum, respectively.

owned, which would otherwise be difficult to purchase owing to their high price even for a medical institution, and for them to be used to train each patient. Moreover, we expect that fabrication of an EMG-BF device by the patient's family members themselves would encourage extensive use of the device at the household level, and raise the quality of EMG-BF therapy at home. The proposed device is a low-cost instrument that offers excellent cost-performance and can improve the quality of rehabilitation at hospital or in the home.

The device was designed by assuming myoelectric signals to be audio signals and inputting them through the microphone port, thus enabling the use of audio display software which is widely available on the Internet. A comparison between audio signals and myoelectric signals showed that the microphone voltage level is usually about 1 mV at most. Because myogenic potentials are about 10 μV, an amplification factor of approximately 50 is sufficient to transform the myoelectric signals to the microphone level. Moreover, with regard to the frequency range, the frequency range of the microphone, which corresponds to that of audible sounds, is 20−20,000 Hz. This encompasses the frequency range for myoelectricity, which is 20−5,000 Hz. Therefore, we can detect the entire range of EMG signals without considering factors such as the sampling frequency. It is possible not only to display EMG signals received through the microphone port on a screen, but also to offer auditory feedback by configuring the software to link with a speaker or headphones.

The proposed device allows two-channel myoelectric signals to be obtained by using a stereo microphone port. In recent years, the effectiveness of training in which specific muscles are contracted while relaxing other muscles, has been confirmed. This training is based on detecting several myogenic potentials in muscles, such as agonist and their antagonist/synergistic muscles. Multi-channel EMG biofeedback devices have also become available in the market. The device developed in this study is also compatible with such training.

The inputs from the microphone port also allow real-time connection to information and communication equipment that is widely available throughout the world. For instance, it would be possible to observe the EMG signals detected at a remote location in real-time or to record and store them using media. This connection also makes it possible to provide remote medical care via Skype; therapists working at a medical institution could provide EMG-BF training to a residential patient while observing the patient's conditions via Skype. Because verifying muscle contractions using palpation is difficult from a remote location, we believe that the proposed EMG-BF device could be effectively used as an EMG monitor in some situations. Patients could also participate in voluntary training, allowing for high-quality training to be conducted at home.

EMG-BF devices are essential for EMG-BF therapy and serve as a basis for neurorehabilitation, which has attracted attention in recent years. However, these devices are not commonly available at medical institutions owing to their high price, hindering the extensive application of EMG-BF therapy. Accordingly, in this study we developed a low-cost EMG-BF device using a microphone port, which people can fabricate by procuring components themselves even if they lack sufficient knowledge and skills related to electronics. The proposed device is expected to help promote the extensive application of EMG-BF therapy and improve the quality of rehabilitation at clinics or homes.

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