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A Review of Devices for Detection of Muscle Activity by Surface Electromyography

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A review of devices for detecting human muscle activity by surface electromyography is presented. The focus is on ready-for-use circuit solutions for EMG sensors for medical investigations from Elemyo (Russia), Grove (China), and CT Retail (China), which are available on the current electronics market. The technical characteristics of modules are analyzed and results obtained by detection of muscle activity on flexion and extension of the hand joints to form a fist are presented. It is concluded that these EMG sensors have potential for use in bionic hand prosthesis control systems.

Introduction

The development of methods for diagnostics of the human nervous and muscular systems has now led to the appearance of a group of electromyographic methods, among which surface electromyography can be distinguished. The use of this method initially involved studies of higher nervous activity and motor functions in humans, age-related characteristics, motor functions in animals, and engineering psychology. Medical use of electromyography consists of identifying the sites and severities of lesions to the neuromuscular apparatus, the spread of pathogenetic processes, the nature of lesions, and the dynamics of their changes. With time, this method has acquired not only purely medical and scientific uses, but also applications in practical tasks such as use in robot technologies and bionic prosthesis control systems, creation of human–computer interfaces, and applications in sports and cosmonautics.

The use of EMG methods in robot technology control systems and, in particular, in bionic prostheses consists of detecting electrical signals transmitted from the operator's nervous system to the limb muscles and the subsequent transformation of these signals into a control signal for the working device. A variety of EMG-based human–machine interfaces have been constructed on this principle. Use of EMG methods in sports and cosmonautics consists of following the responses of the human body, particularly the nervous system and muscular apparatus, to high levels of physical and psychological loading to develop optimum training programs. This method is widely used for the rehabilitation of patients with various pathologies of the nervous and motor systems.

The appearance of this method required transition from large, high-precision medical devices to miniature electronic circuits. Contemporary electronic circuits used for detecting human muscle activity signals differ in their design, are based on different components, and have unique sets of technical characteristics.

Materials and Methods

EMG sensors commercially available from a number of manufacturers were considered. Sensors from different manufacturers are intended for different applied tasks. The most widely used models are: the Grove EMG Detector from Seeed Studio (China), the MYO v1.2 EMG module, the MH-BPS102 EMG/ECG sensor from Elemyo (Russia), and the ECG measurement module based on an AD8232 sensor which can be used as an EMG sensor, from CT Retail (China).

Comparative analysis of sensors was run using data from the manufacturers. The components used for con-

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struction of modules were considered, along with the presence or absence of high- and low-pass filters, signal amplification, the operating principles used for designing the main components of sensors, and functional capacities in terms of detecting EMG signals. Test conditions for comparative testing of sensors involved positioning of electrodes on the right forearm at the locations of the muscles responsible for hand flexion.

The Grove EMG Detector is constructed on the basis of two OPA333 low-noise operational amplifiers with zero drift and an INA331IDGKT differential instrumentation amplifier [1]. Each of these components is based on the rail-to-rail principle, expanding the output signal range to the U_{supply} level and providing more accurate detection. This feature also allows low voltage to be used to power the whole circuit. The supply voltage for the circuit is in the range 3.3-5 V. The recommended supply voltage is 3.3 V, such that the sensor can be connected directly to the microcontroller. Electrodes are connected using a 3.5-mm mini jack. The noise level of the amplifier at frequencies of 0.01-10 Hz is 0.1 μV, which at an output analog signal level of 0-3.3 V gives quite high EMG measurement accuracy [2]. Single-use replaceable electrodes attached by means of a button-type quick release fitting are used.

The drawbacks of this module are as follows. The limited bandwidth of the filter installed in the circuit produces inaccuracy in transmission of the signal detected and makes low-amplitude signals undetectable. A second drawback is the use of rail-to-rail units, as the constructional features of this circuit can introduce distortions when working with alternating signals. The lack of galvanic decoupling along the power supply line and the connection of electrodes using unscreened cables are disadvantages, as they can produce noise and interference from the power supply or external sources of noise, such as various pieces of electronic equipment.

The MYO v1.2 EMG module is a device in a casing ready for use in combination with various microcontrollers. The module has a rectangular casing with rounded edges of size 45.0 × 16.0 × 7.5 mm with electrodes on one side and a 60-cm cable. The supply voltage of the module is 4.5-5.5 V, the standard being 5 V. The module has a low supply current of 3 mA and two analog outputs, $OUT_{3.3\text{V}}$ and $OUT_{5\text{V}}$, with output voltage ranges of 0-3.3 and 0-5 V, respectively. The base gain of the sensor is 1000 V/V and can be increased by the sensor's SPI interface by factors of 2, 4, 5, 8, 10, 16, and 32. The bandwidth of the built-in filter is 8-200 Hz. The sensor electrodes are made of medical stainless steel and are firmly fixed to the casing. The sensor is connected to the microcontroller, which in turn is connected to a computer operating from the domestic power network, using a USB isolator providing galvanic decoupling required for protection from network noise at 50/60 Hz [3, 4].

The MYO v1.2 EMG module is constructed on the basis of two printed circuit boards. The first, responsible for primary amplification of the signal, has two TS27L2I low-power precision operational amplifiers (Texas Instruments, USA). These amplifiers have low supply current (10 μA) [5]. The second board bears another TS27L2I operational amplifier, an ADR03A reference voltage source providing the board with a reference voltage of 2.5 V, an AD623A instrument amplifier operating on the rail-to-rail principle and responsible for changes in the signal gain, and an MCP652 operational amplifier with automatic signal calibration providing signal filtering [6].

An important feature of the EMG module is dry skin contact, allowing the EMG signal to be detected without preliminary preparation or use of special substances increasing the electrical conductivity of skin.

The fixed sites of the electrodes are both an advantage and a disadvantage of the EMG module. On the one hand, they simplify electrode positioning on the working surface, while on the other they decrease the flexibility of use of the sensor because the positions of the electrodes cannot be changed relative to each other when this is needed. Drawbacks also include the use of rail-to-rail elements, which can produce distortion of the signal detected.

The MH-BPS102 EMG sensor is advertised by the manufacturer as a universal solution suitable for detecting EMG and ECG signals. The sensor is a printed circuit board bearing components on one side and electrodes on the other. The board size is 19.1 × 14.5 × 3.0 mm, making it more compact than the MYO v1.2 module discussed above. The board supply voltage is 3.2-5.5 V, with a recommended voltage of 3.3 V, allowing the sensor to be powered directly from the microcontroller, though as in the case of the MYO v1.2 module, the sensor requires galvanic decoupling from the supply network for protection against network noise and interference from secondary power supplies [7]. The board supply current is 3 mA, which is economical in relation to the battery supplying the device including the sensor. The output signal is analog with the maximum range equal to the power supply voltage of the sensor. The sensor supports dry skin contact and does not require special preparation of the contact site. The sensor includes a filter with a bandwidth of 8-200 Hz and a gain which is controllable via the SPI interface. The standard gain is 1000 V/V. It can be increased by factors of 2, 4, 5, 8, 10, 16, and 32 [8].

The primary amplification unit for the signal from the sensor electrodes is constructed on the basis of two (one for each signal electrode) OP2177 two-channel precision low-noise operational amplifiers with low input bias current from Analog Devices (USA). The sensor includes an AD8275 differential amplifier with the common-mode rejection of 80 dB to suppress signal distortions and an MCP6S21 programmable amplifier with a bandwidth of 12 MHz from Microchip Technology (USA), which provides for changes in signal gain [9]. This amplifier has characteristics such as low noise power density (10 nV/Hz$^{1/2}$) at 0-10 kHz, low gain error of no more than 1%, and supply current of 1 mA. The device is constructed on the rail-to-rail principle [10]. The electrodes are made of medical stainless steel.

The drawbacks of this sensor, like those of the MYO v2.1 module, are associated with the rigidly positioned electrodes and use of the rail-to-rail principle in the AD8275 differential amplifier and MCP6S21 amplifier.

The last EMG module to be considered is the AD8232 chip from Analog Devices with a set of passive components. The AD8232 chip is a specialized microcircuit for measuring the ECG and other biopotential signals. Its main feature is the ability of the chip to detect, amplify, and filter biopotential signals in the presence of introduced noise and interference due to the movement of the body or large distances between the electrodes and the sensor board. The supply current of the chip is 170 μA and the noise rejection level is 80 dB at frequencies of up to 60 Hz. The device can operate with two or three electrodes; it provides high gain (100) and has a two-pole adjustable high-pass filter and a three-pole adjustable low-pass filter with adjustable gain. The chip supply voltage is 2-3.5 V. The chip is built on the rail-to-rail principle and has an integrated reference buffer generating a virtual ground. The output is analog [11].

The drawbacks of this module include the lack of galvanic decoupling from the power supply, the need to use unscreened cable to connect the electrodes, and a long mean signal level settling time.

It follows from the review of the component base of modules for detection of EMG signals that they make wide use of components built on the rail-to-rail principle. The design features of the input stages of these components, consisting of N- and P-channel transistors, can induce signal distortion on passage through the cascade switching boundary. To eliminate this characteristic of the working of the operational amplifiers and to increase signal detection accuracy, EMG modules should use operational amplifiers with integrated boost regulators allowing operation over the entire voltage range using only one stage [12].

Results

Tests of the EMG modules and sensors discussed above produced the following results. Tests were run using Arduino IDE software, version 1.8.5. The test conditions for each EMG sensor were as similar as possible in terms of parameters such as the sensor/electrode positions on the hand and the movements made by the hand – clenching the hand into a fist followed by unclenching. Curves illustrating the operation of EMG sensors were obtained using Arduino IDE software functions – a serial plotter drawing graphs based on data captured by a specified analog input of the microcontroller.

On plots, data on the abscissa show time points from activation of the plotter function to the moment at which EMG signal values were recorded from the screen. The values on the abscissa are in units of 1/1000 s.

The ordinate shows values for the signal at the analog input over the range from 0 to U_{supply}, as the EMG sensors considered here are built on the rail-to-rail principle. The values on the ordinate are in units of 1/100 V.

Let us consider the results of tests of EMG modules. The right-hand parts of figures show data plots obtained from sensors and the left-hand parts show photographs of the sensors at the moment of testing.

Figure 1 shows the results of tests of the Grove EMG Detector.

The moment of maximum hand muscle tension on clenching the fist is clearly apparent on this plot as the tallest vertical peak, while the moment of muscle relaxation after compression is seen as descending peaks and the moment of unclenching is apparent as a negative peak.

Figure 2 shows the results of tests of the MYO v1.2 EMG module.

The signal obtained from the MYO v1.2 EMG module has more signal peaks and troughs than the signal detected using the Grove EMG Detector. This is due to the greater rate of interchange of data with the microcontroller, which has the result that the EMG module is able to transmit every change in signal value without fusion with the neighboring values. Apart from the maximum-amplitude peak, seen at the moment of maximum muscle tension, the plot shows muscle activity preceding clenching of the fist. The operation of hand muscles not associated with clenching is also seen as changes in signal levels after the main cascade of peaks and troughs. This is evidence of the high sensitivity of the EMG module, which allows detection of signals even from muscles not involved in the movement being performed.

Figure 3 presents data obtained using the MH-BPS102 sensor.

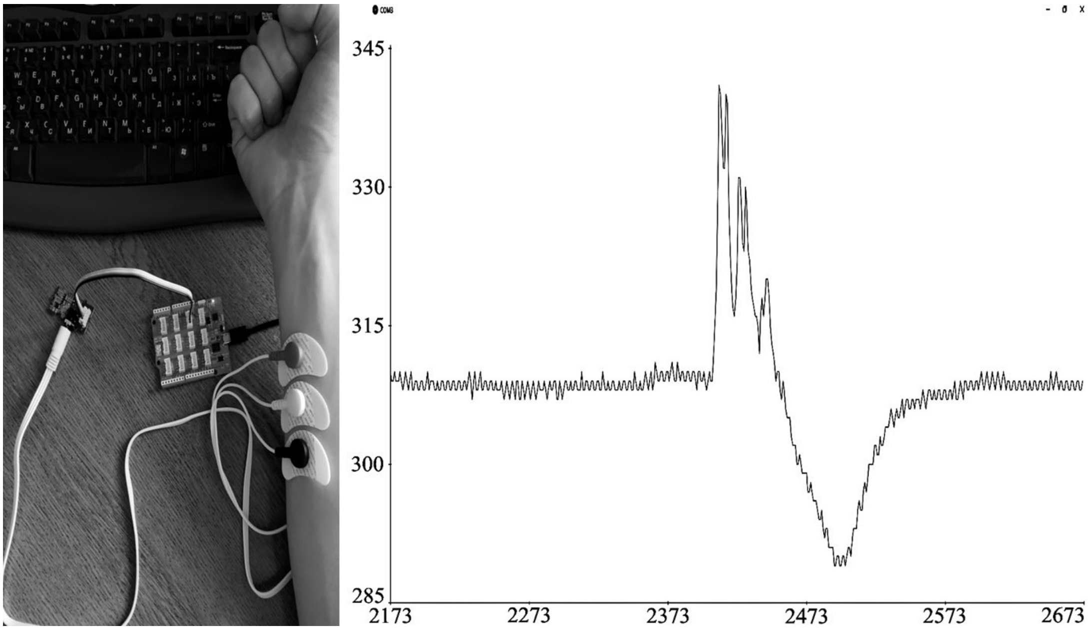

Fig. 1. Experiment and plot of EMG signal obtained using the Grove EMG Detector.

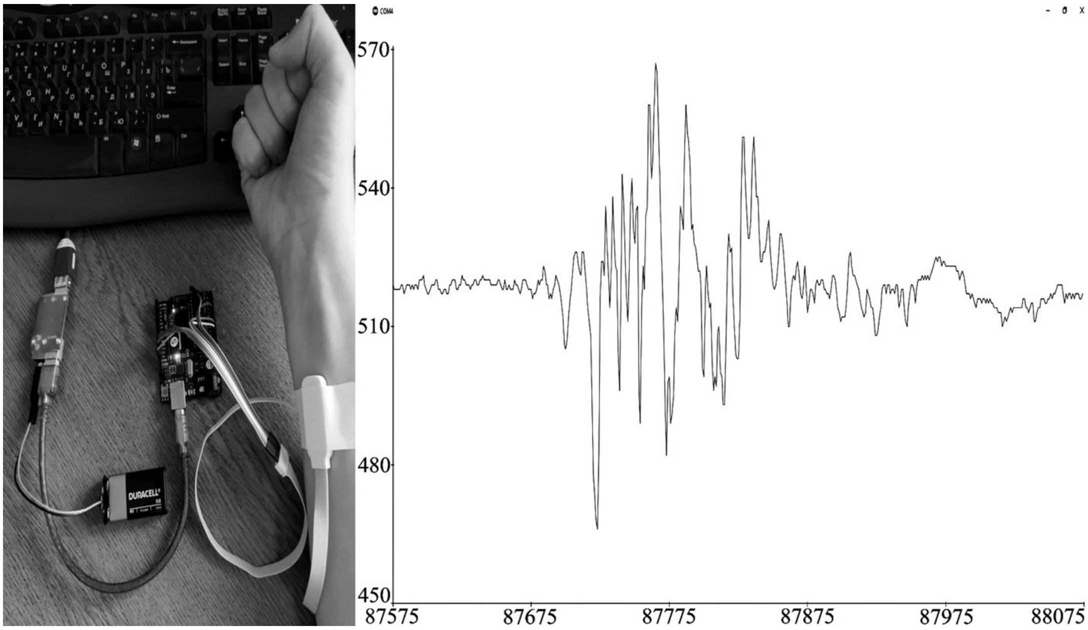

Fig. 2. Experiment and plot of EMG signal obtained using the MYO v1.2 EMG module.

As with the preceding module, the MH-BPS102 has a higher data interchange rate with the microcontroller, providing more precise signal shape. Plots clearly show muscle tension on clenching, along with transition to the relaxation state after clenching. Overall, the sensor behaved at the same level as the MYIO v1.2 EMG module, though the level of interference introduced by other muscles, not involved in the movement, was lower due to the smaller size of the sensor and electrodes.

Figure 4 shows a plot of the EMG signal obtained using the EMG module based on the AD8232 chip.

This plot clearly shows the moment of clenching of the hand and subsequent relaxation. The characteristics of the signal from the sensor were similar to those of the Grove EMG Detector. Signal distortions occurred as a

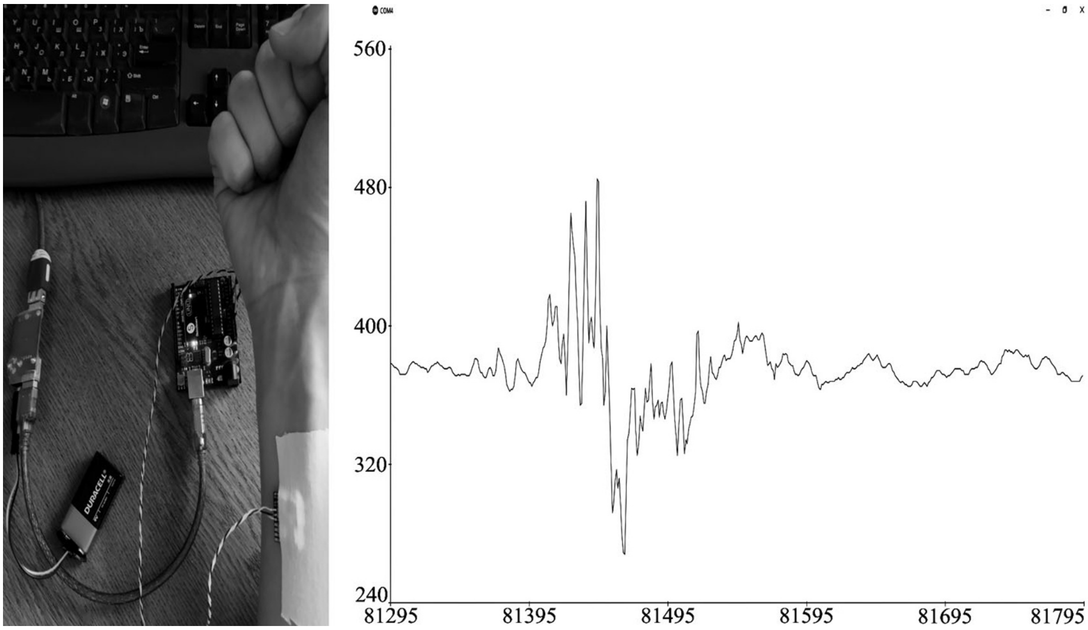

Fig. 3. Experiment and plot of EMG signal obtained using the MH-BPS102 EMG module.

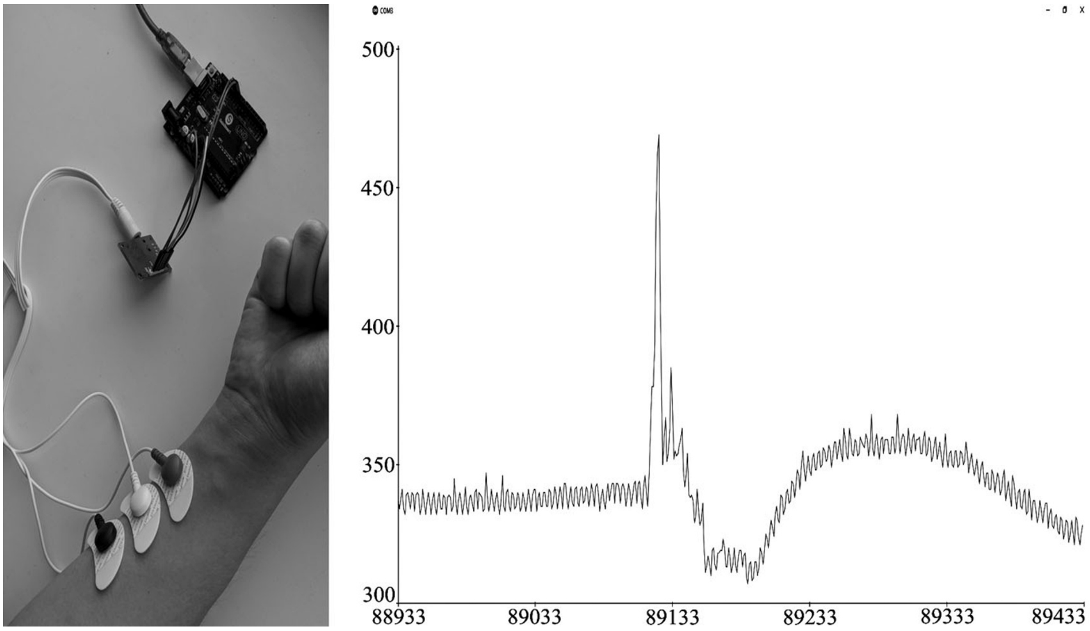

Fig. 4. Experiment and plot of EMG signal obtained using the AD8232 EMG module.

result of the low rate of data interchange, with fusion of neighboring peaks; the sensor was also inadequate in terms of the long time required to establish the mean signal level after connection to the hand, which was 3-5 s.

The obtained results show that the Grove EMG Detector and AD8232 are less effective for noise filtering from the signal than the other modules assessed.

Apart from the functional and technical parameters of the modules discussed here, economic considerations must also be addressed. Each of the modules assessed is on the open market, so comparisons were carried out on the basis of retail price per unit for each module.

Prices of EMG modules are:

1) Grove EMG Detector: 4400 rubles;
2) MYO v1.2 EMG module: 3950 rubles;
3) MN-BPS102 EMG/ECG sensor: 1900 rubles;
4) AD8232 sensor-based ECG measurement module: 740 rubles.

Thus, the lowest-cost item is the ECG module based on the AD8232 chip. However, in terms of its functional characteristics this module is inferior to the MYO v1.2 and the HM-BPS102. In addition, use of the AD8232-based module, like the Grove EMG Detector module, requires utilization of single-use surface electrodes for attachment to subjects. This increases their cost of use. The MYO v1.2 and MH-BPS102 modules, conversely, use built-in multiuse electrodes. The MYO v1.2 EMG detector module and the H-BP102 EMG/ECG sensor have comparable functional capacities. However, the cost of the MH-BPS102 is twice that of the MYO v1.2. The MH-BPS102 is positioned as universal EMG/ECG sensor. This comparison leads to the conclusion that the MH-BPS102 sensor is the most suitable in terms of economic parameters.

Conclusions

Comparative analysis of various EMG sensors and EMG modules available on the market showed that all these sensors detected EMG signals on muscle contraction. The most accurately detected signals were obtained from sensors with multiple amplification levels, in terms of both the signal at one of the detection electrodes and the total signal from both electrodes, as well as controllable gain allowing adjustment for different signal levels depending on the speed and strength of muscle contraction. Another important factor for EMG signals is the employment of a signal filtering system for high and low frequencies, allowing interference from external sources to be rejected; another is the use of galvanic decoupling of the power supply to eliminate network interference at 50 Hz. Furthermore, the sensor must have a high rate of data interchange with the microcontroller, as low interchange speeds lead to distortion of signal shape. This can have adverse impact on the operation of the control system, which requires an accurate detected signal shape for correct operation. Of the sensor models presented and analyzed, MH-BPS102 and MYO v1.2 are most completely corresponding to the requirements and capable of being used as the basis of bionic prosthesis control systems.

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