

BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 72 (76), Numărul 3, 2026
Secția
CONSTRUCȚII DE MAȘINI
DOI: 10.2478/bipcm-2026-0024

A COMPARATIVE STUDY ON THE OPTIMIZATION OF EMG SYSTEMS FOR CONTROLLING MYOELECTRIC PROSTHETICS

BY

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Received: July 20, 2026

Accepted for publication: August 4, 2026

Abstract. This paper presents a comparative analysis of two analog modules for acquiring biological electrical signals, the AD8232 and the SEN0240, with a view to their use in an experimental myoelectric control system for an upper limb prosthesis. The study stems from the need to identify a module capable of autonomously distinguishing between muscle rest and voluntary contraction, so that the acquired signal can be used to control a shape-memory (alloy) actuator via a microcontroller and an N-MOSFET transistor. The comparison focuses on criteria such as signal stability, ease of integration with Arduino, sensitivity to artifacts, and practical utility for controlling an actuator. The experimental results indicate that the SEN0240 offers a more direct alignment with the requirements of a myoelectric application, while the AD8232 can be used to detect bioelectric signals but has some drawbacks. Thus, this paper justifies the selection of the SEN0240 module for the continued

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development of the experimental system for controlling the actuator using myoelectric signals.

Keywords: myoelectric, shape-memory alloy, upper limb prostheses, muscle contraction, multi-criteria decision analysis.

1. Introduction

Myoelectric control represents an important direction in the development of upper limb prostheses, as it allows the use of muscle activity to generate actuation commands. In this context, a review of the literature was conducted to select an accessible and usable module for controlling a system that includes shape-memory material.

In the study on the development of a hand prosthesis inspired by human anatomy (Dunai *et al.*, 2025), OYMotion and SparkFUN MyWare AT-04-001 sensors were used and compared. Circuits based on AD8232 modules were developed to record shoulder muscle activity in a person with shoulder disarticulation (Guzmán-Quezada *et al.*, 2024). In the “Touch Hand 4.5” project (Moodley *et al.*, 2022), muscle contractions were processed using electrodes and BITalino EMG modules, with the signal being used in the control system of a low-cost prosthetic hand. In another study, eight SEN0240 sensors were arranged in a circular pattern (Pieprzycki *et al.*, 2025) on the forearm for amplified multichannel recording of EMG signals and hand gesture classification. Furthermore, in an exoskeletal glove system for hand function rehabilitation (Chen *et al.*, 2021), the Cyton OpenBCI board was used to acquire EMG signals from four locations on the forearm.

The experimental analysis was limited to a comparison between the AD8232 and the SEN0240, as both are compact, affordable, and easy to integrate with Arduino-type systems. The other solutions identified, such as MyWare, BITalino, and Cyton OpenBCI, differ significantly in terms of integration level, number of channels, complexity, and cost, which would have reduced the comparability of the results.

The study examines the connection diagrams, signal conditioning, and the suitability of each module for controlling a shape-memory actuator in an experimental system.

2. Presentation of the Analyzed Modules

2.1. AD8232 Module

AD8232 module (Fig. 1) is an integrated circuit for conditioning bioelectrical signals, designed primarily for electrocardiographic (ECG) applications and other measurements based on biological signals. According to the datasheet (Analog Devices, 2020), the device is intended for the acquisition,

amplification, and filtering of small bioelectric signals, including in situations involving movement or with electrodes placed considerably apart.

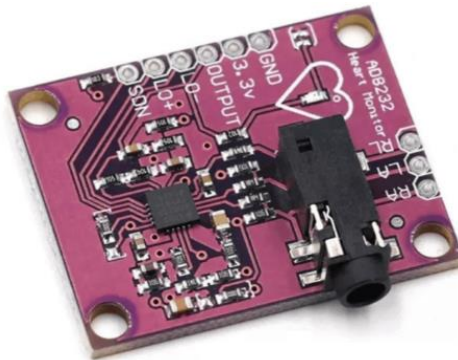


Fig. 1 – AD8232 module.

In comparative experiments, AD8232 module was used to monitor bioelectric signals and to test the possibility of detecting muscle contraction. In the configuration used, the module was powered at 3.3V, and the analog output was connected to pin A0 of the Arduino Uno board. This configuration depended on the placement of three electrodes, which were necessary for signal acquisition.

Although the module allowed for the detection of signal variations, its use for myoelectric control was limited by sensitivity to electrode contact and the quality of the recorded signal (detected artifacts).

2.2. SEN0240 Module

SEN0240 is an analog module (Fig. 2) designed for acquiring surface muscle signals mainly electromyographic signals (EMG). The module uses dry electrodes and signal conditioning circuits, providing an analog output signal compatible with the analog inputs of a microcontroller (such as an Arduino).

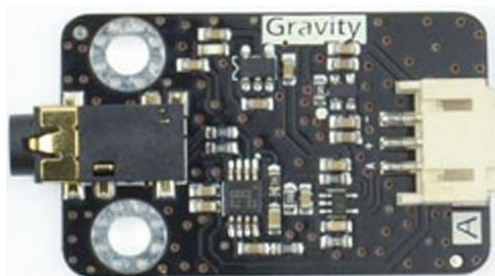


Fig. 2 – SEN0240 module.

The documentation provided by the manufacturer (DFRobot, 2024) specifies an analog output with a reference voltage of approximately 1.5 V and an output range of approximately 0–3.0 V, with the signal amplitude depending on the level of muscle contraction.

For this comparison, the same Arduino UNO microcontroller was used; the SEN0240 has only three main connections: the 5V power supply, the common ground, and the analog output connected to pin A0.

2.3. Similarities and Differences between the Two Modules

To supplement the comparative study, Table 1 outlines the similarities and differences between the two modules.

Table 1
Presentation of the Similarities and Differences between the AD8232 and SEN0240 Modules

Similarities	Differences
Both carry an analog signal that can be read by the Arduino through an analog input.	The AD8232 can detect the detachment of electrodes from the skin.
Both modules require a power supply and a shared GND connection to the microcontroller.	Different power supply: The AD8232 requires 3.3V; the SEN0240 requires 5V.
Both modules require software signal processing to distinguish between muscle rest and contraction.	The AD8232 requires the placement of three gel electrodes. The SEN0240 uses a single dry electrode.
Both modules are sensitive to sudden movements, the quality of skin contact, and the computer's power source.	SEN0240 allowed for lower detection thresholds to be set in the Arduino IDE, due to its more stable signal.
Both modules can be integrated into an Arduino-MOSFET-transistor-actuator system.	The SEN0240 is easier to install due to its reduced number of connections (see Table 2).
Both modules are used to acquire electrical signals from the skin's surface.	Different factory configurations: AD8232 for ECG signals; SEN0240 for EMG signals.
Both serve to acquire/control, not to directly power the actuator.	The AD8232 uses its pins to detect electrode detachment, which is useful in ECG applications where continuous electrode contact is critical.

2.4. Wiring Diagrams Used for Each Module

To compare the modules, the same Arduino UNO microcontroller was used, so that any observed differences could be attributed to the characteristics of the bioelectric signal conditioning modules.

Table 2
Presentation of the two diagrams for easier visualization

AD8232	SEN0240
AD8232 OUTPUT → Arduino A0	SEN0240 A → Arduino A0
AD8232 3V → Arduino 3.3V	SEN0240 + → Arduino 5V
AD8232 GND → Arduino GND	SEN0240 - → Arduino GND (common)
AD8232 LO+ → Arduino D8	
AD8232 LO- → Arduino D9	
AD8232 SDN → Arduino 3.3V	

2.5. Preliminary Conclusions

Up to this point in the paper, it was presented that both modules can be used to detect muscle activity, but the differences between the modules become apparent.

From the connection diagrams (Table 2), it can be seen that the SEN0240 module has a significant practical advantage over the AD8232, as it requires only three main connections: analog signal, power supply, and ground. It uses a compact board equipped with three metal contacts, assembled into a single unit that is applied to the skin.

AD8232 uses more connections, including the “LO+”, “LO-” and “SDN” pins, which increases the complexity of the assembly.

The simplicity of the SEN0240 module’s connection reduces the risk of errors, facilitates rapid integration with the Arduino UNO board and eliminates the additional costs associated with single-use gel electrodes. In addition, setting up the three electrodes takes longer, and repeating the experiments under the same conditions is more difficult, since the position of each electrode must be reproduced as precisely as possible. These aspects are important in an experimental myoelectric system, where the stability of the setup and signal repeatability directly influence actuator control.

3. The Role of Sensors in a Myoelectric Prosthesis

In the literature, the widespread use of EMG signals in prosthetics is supported (Yadav and Veer, 2023). Also, the importance of reliable acquisition of EMG signals is highlighted for obtaining intuitive control, emphasizing in (Chen *et al.*, 2023) the role of myoelectric signals captured by sensors in recognizing motor intentions and in implementing control strategies for hand prostheses.

In a myoelectric prosthesis, the sensor does not merely detect the presence of an electrical signal; it must also provide information that is stable enough to enable repeatable control of the actuator. From the literature (Li *et al.*, 2021), we understand that the performance of a myoelectric system depends on a rigorous sequence of stages consisting of acquisition, processing, and control; at the component level, we focus on electrodes, amplification, filters, the decision algorithm, and response time.

For a myoelectric upper-limb prosthesis, the important criteria for the acquisition module are:

1. compatibility with the EMG signal;
2. clear differentiation between rest and contraction;
3. sensitivity to electrode placement and signal stability over time;
4. low sensitivity to sudden movements;
5. ease of connection to the microcontroller and connection complexity;
6. the ability to operate in real time;
7. command repeatability;
8. the cost and availability of the module.

4. Design of a Circuit for Controlling Shape-Memory Material

A separate power stage was used for the experimental actuation of the shape-memory material, since the current required for heating via the Joule effect is much greater than what an Arduino pin can directly supply. The digital control signal comes from the Arduino, which controls a MOSFET transistor, and the current source used for heating was created from a separate power supply consisting of 3200mAh 3.7V batteries. In addition, to prevent unwanted battery discharge, an ON/OFF switch was installed to isolate the power stage from the rest of the circuit. Fig. 3 presents the general diagram of the experimental circuit described above.

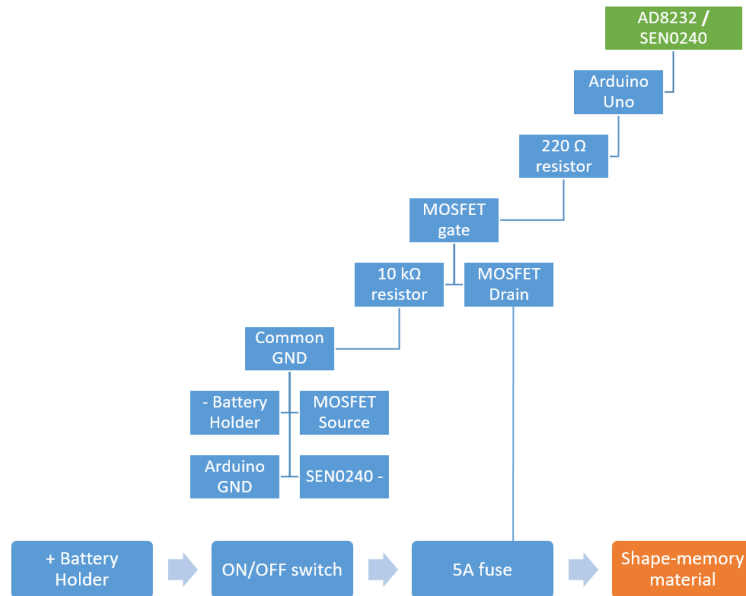


Fig. 3 – General Diagram of the Experimental Circuit.

5. Comparison of the Signals Acquired by Each Module

To capture the myoelectric signals, the electrodes of the two modules had to be positioned on the skin's surface as follows:

- AD8232 module electrodes: red on the active muscle of the forearm, toward the elbow; yellow on the same muscle, toward the wrist; green on a more neutral area - elbow (Fig. 4).

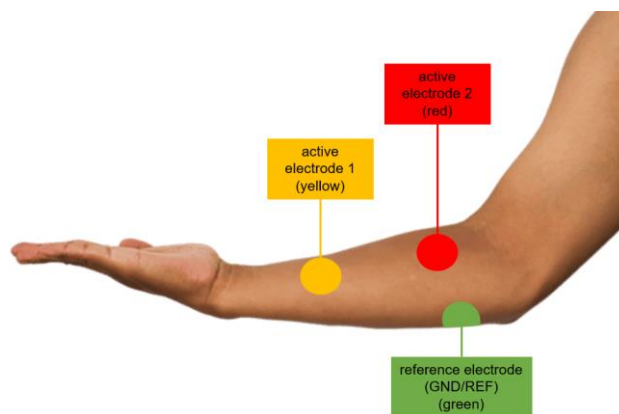


Fig. 4 – Positioning of the three electrodes of the AD8232 module.

- SEN0240 module electrode: on the active muscle of the forearm, with the dry electrode in contact with the skin (Fig. 5).

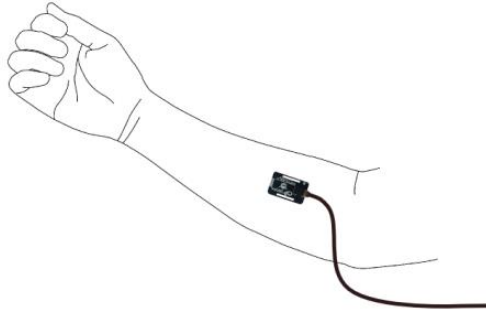


Fig. 5 – Electrode Placement for the SEN0240 Module (DFRobot, 2024).

Using the Serial Plotter function in the Arduino IDE, graphs were generated under similar conditions during muscle contraction.

In the following figures (Fig. 6 and Fig. 7) are illustrated examples of graphs of the muscle at rest obtained as follows: the vertical axis represents signal amplitude and the horizontal axis represents the number of readings.

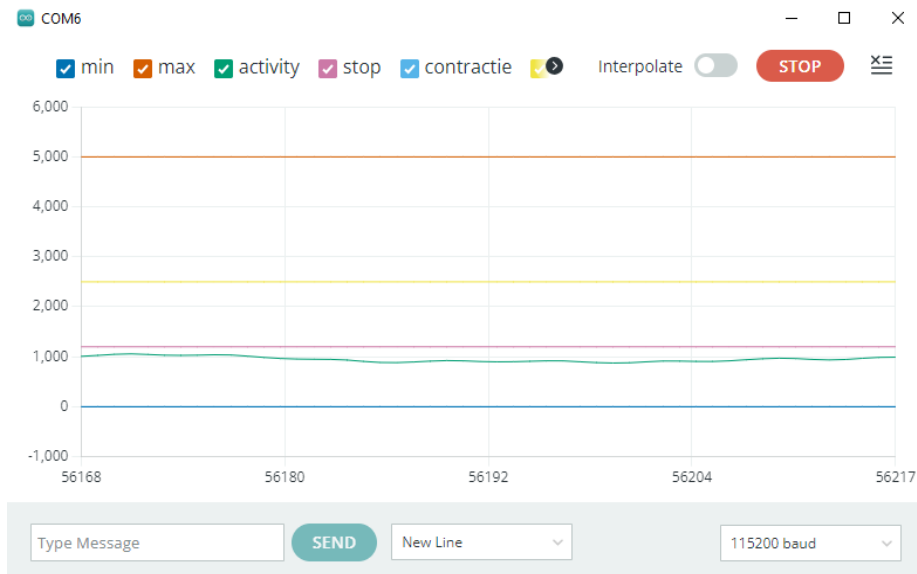


Fig. 6 – Graphic obtained using AD8232 module.

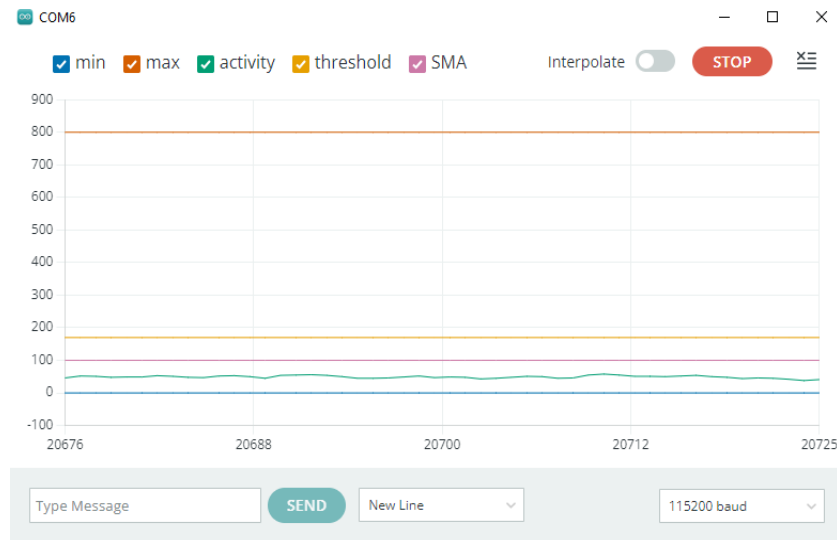


Fig. 7 – Graphic obtained using AD8232 module.

A comparison of the graphs obtained at rest shows that both modules provide a relatively stable signal without sudden variations, but the processed signal level differs significantly between the two modules (the green line, labeled “activity” represents the muscle signal).

The following figures show examples of graphs of muscle activity during contraction, obtained as follows:

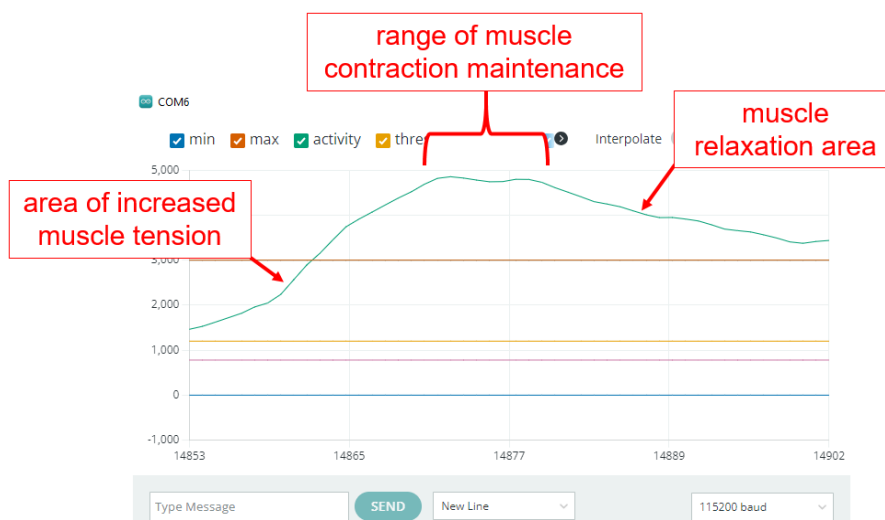


Fig. 8 – Graphic obtained using AD8232 module.

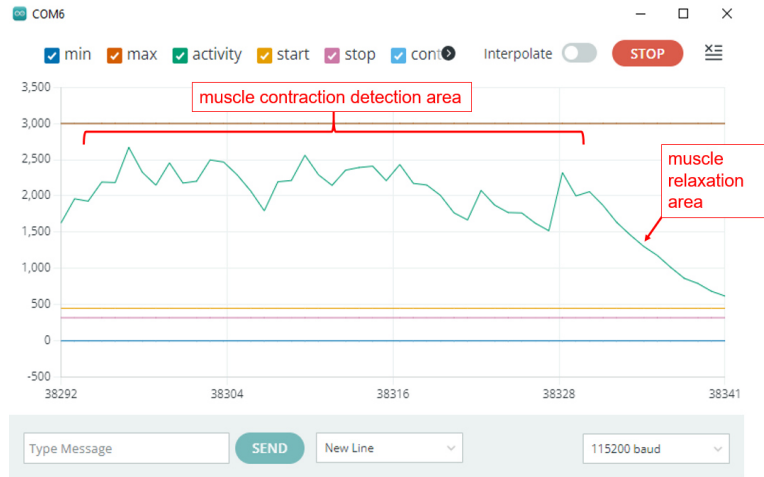


Fig. 9 – Graphic obtained using AD8232 module.

SEN0240 has a lower resting signal level, which facilitates more precise identification of subsequent contractions. In the case of the AD8232, the resting signal is at a higher level, a factor that can complicate the establishment of a control threshold applicable even to small contractions.

The graphs recorded during muscle contraction (Fig. 8 and

Fig. 9) show that both modules detect variations in bioelectric activity. However, the AD8232 exhibits a more gradual and less well-defined response, which can make it difficult to establish a clear control threshold. In contrast, the SEN0240 exhibits a more clearly defined contraction zone and a sharper transition to relaxation, which is advantageous for myoelectric control.

These comparisons support the use of the SEN0240 as the more suitable module for the proposed experimental application.

6. Proposed Method of Analysis

To compare the two modules, a multi-criteria analysis will be used, employing a decision matrix. In the literature (Taherdoost and Madanchian, 2023), Multi-Criteria Decision Analysis (MCDA) is described as one of the most accurate decision-making methods and can be considered a true evolution in the decision-making field, as it allows the simultaneous evaluation of multiple criteria. This method allows for the evaluation of each module based on several technical criteria relevant to the proposed application. This method examines aspects such as the simplicity of the connection scheme, compatibility with the EMG system, signal stability during testing, the ability to distinguish

between muscle rest and contraction, and the possibility of using the signal to control an actuator.

Each module was analyzed against the same criteria to allow for an objective comparison.

Proposed rating scale:

- 1 = poor performance / inadequate
- 2 = limited performance
- 3 = acceptable performance
- 4 = good performance
- 5 = very good performance.

This method is useful because the choice of acquisition module depends not only on the presence of an analog output signal, but also on stability, repeatability, and suitability for controlling a potential myoelectric prosthesis.

7. Multi-criteria analysis

The multi-criteria analysis, based on the criteria listed in paragraph 3 and the ratings provided in accordance with paragraph 6, is presented in the table below.

Table 3
Multi-criteria analysis

Analyzed Criterion	Rating for AD8232	Rating for SEN0240	Remarks
Compatibility with EMG signals	3	5	The AD8232 is primarily designed for ECG, but it can also detect muscle contractions with the appropriate settings. The SEN0240 is the dedicated EMG module.
Unambiguous detection of rest–contraction	2	5	SEN0240 allowed for the observation of muscle contractions in preliminary tests with fewer artifacts in the detected signal.
Connection Complexity	3	5	SEN0240 requires only power, an analog output, and ground.
Experimental stability and sensitivity to electrode placement	3	4	The AD8232 was more sensitive to electrode placement and mechanical contact.
Integration with Arduino	4	4	Both can be read in the same way.
Motion sensitivity	2	3	Both are sensitive to movement, but SEN0240 stays in place more securely

			and is better suited for muscle contraction.
Real-Time Use	4	4	Both modules detected a signal in real time
Cost / Affordability	5	3	The AD8232 is less expensive and available in Romania. The SEN0240 was more expensive and was shipped from the U.S.

Table 4 presents the results of the multi-criteria analysis.

Table 4
Results obtained after multi-criteria analysis

Modules	Average of the Ratings obtained
AD8232	3,25 out of 5
SEN0240	4,125 out of 5

The results of the multi-criteria analysis indicate that SEN0240 module is better suited for the proposed application, particularly due to its “cleaner” differentiation between the resting state and muscle contraction. However, the AD8232 module may be useful in future research for simultaneously studying multiple contractions from different muscles or in applications involving electrocardiographic signals.

8. Conclusions

The analysis conducted highlights the fact that the AD8232 and SEN0240 modules can be used to acquire bioelectric signals, but their behavior differs in the context of myoelectric control applications.

The SEN0240 module demonstrated simpler integration and a more suitable response for detecting muscle activity. The reduced number of connections, its specific design for electromyographic signals, and the clearer distinction between rest and contraction make it more suitable for controlling a prosthetic system.

Thus, following testing and multi-criteria analysis, SEN0240 can be considered more suitable for the continued development of a prosthetic system, providing a more practical basis for detecting muscle contraction that can be converted into a command for the actuator.

The AD8232 remains useful for monitoring other signals, depending on the progress of the research; in fact, we are even considering combining the two modules for future experiments. Furthermore, as a future research direction, we are considering that the finite element method can be effectively used to predict the impact behavior of composites, as has been demonstrated (Ionesi *et al.*,

2021). We intend to conduct mechanical tests on our own models to analyze impact performance, taking into account the results obtained for the Steel-Kevlar and Twaron reinforcement combinations (Ionesi *et al.*, 2012).

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STUDIU COMPARATIV PRIVIND OPTIMIZAREA SISTEMELOR EMG PENTRU CONTROLUL PROTEZELOR MIOELECTRICE

(Rezumat)

Lucrarea prezintă o analiză comparativă a două module analogice de achiziție a semnalelor biologice electrice, AD8232 și SEN0240, urmărind utilizarea acestora într-un sistem experimental de comandă mioelectrică pentru o proteză de membru superior.

Studiul pornește de la necesitatea identificării unui modul capabil să diferențieze în mod autonom starea de repaus muscular de contracția voluntară, astfel încât semnalul obținut să poată fi utilizat pentru comanda unui actuator cu memorie de formă prin intermediul unui microcontroler și al unui tranzistor N-MOSFET. Compararea urmărește criterii precum stabilitatea semnalului, simplitatea integrării cu Arduino, sensibilitatea la artefacte și utilitatea practică pentru controlul unui actuator.

Rezultatele experimentale indică faptul că SEN0240 corespunde mai bine cerințelor unei aplicații mioelectrice, în timp ce AD8232 poate fi utilizat pentru evidențierea unor semnale bioelectrice, dar prezintă unele dezavantaje. Astfel, lucrarea fundamentează alegerea modulului SEN0240 pentru continuarea dezvoltării sistemului experimental de comandă a actuatorului prin semnale mioelectrice.