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УМНЫЕ ПРОТЕЗЫ И ИХ ВОЗМОЖНОСТИ

Аннотация. *Умные протезы представляют собой важное достижение биомедицинской инженерии, объединяющее современные механические системы, электронные датчики, искусственный интеллект и технологии взаимодействия человека с машиной. В отличие от традиционных протезов, интеллектуальные протезы способны интерпретировать биологические сигналы, распознавать намерения пользователя, адаптироваться к различным видам деятельности и обеспечивать улучшенные функциональные возможности. Системы миоэлектрического управления используют электрические сигналы мышечной активности для управления движениями протеза, а алгоритмы машинного обучения позволяют повысить точность распознавания жестов и прогнозирования движений. Сенсорные технологии также обеспечивают регулирование силы захвата, контроль положения*

конечности и адаптацию протеза к меняющимся условиям окружающей среды.

Ключевые слова: *умные протезы, бионические конечности, искусственный интеллект, миоэлектрическое управление, электромиография, машинное обучение, сенсорная обратная связь, реабилитация.*

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SMART PROSTHESES AND THEIR CAPABILITIES

Abstract. *Smart prostheses represent an important achievement in biomedical engineering, combining advanced mechanical systems, electronic sensors, artificial intelligence, and human–machine interaction technologies. Unlike conventional prosthetic devices, intelligent prostheses can interpret biological signals, recognize movement intentions, adapt to different activities, and provide improved functional performance. Myoelectric control systems use electrical signals generated by muscle activity to control prosthetic movements,*

while machine learning algorithms can improve gesture recognition and the accuracy of movement prediction. Sensor technologies also support the regulation of grip force, the monitoring of limb position, and the adaptation of prosthetic devices to changing environmental conditions.

Keywords: *smart prostheses, bionic limbs, artificial intelligence, myoelectric control, electromyography, machine learning, sensory feedback, rehabilitation.*

Introduction

The development of modern biomedical engineering has created new opportunities for restoring lost motor functions and improving the independence of people with physical disabilities. Among the most significant innovations in this field are smart prostheses, which integrate mechanical engineering, electronics, computer science, robotics, and biological signal processing. Traditional prostheses primarily perform a structural or mechanical function. Although they can compensate for the absence of a limb, their capabilities may be limited in situations requiring precise movements, adaptive control, or interaction with different objects. Smart prostheses, by contrast, incorporate electronic sensors and intelligent control algorithms that enable more flexible and responsive operation.

Materials and Methods

This article is based on a narrative review of scientific publications concerning intelligent prosthetic systems, myoelectric control, machine learning, sensory feedback, and human–prosthesis interaction. Relevant literature was examined to identify major technological approaches, functional advantages, existing limitations, and prospective directions of development. The analysis focused on peer-reviewed review articles and research publications addressing upper-limb and lower-limb prostheses. Comparative and descriptive methods

were used to summarize the principal characteristics of smart prostheses and assess their potential applications in rehabilitation.

Results and Discussion

Technological Foundations of Smart Prostheses

Smart prostheses consist of several interconnected components that work together to convert the user's intentions into physical movement. Their architecture generally includes a mechanical structure, sensors, a control unit, actuators, a power supply, and, in some systems, a sensory feedback interface.

Sensor technologies: Sensors are essential for collecting information about muscle activity, movement, pressure, and the surrounding environment. The collected data are processed by a control system to determine the appropriate prosthetic response. Electromyography (EMG) is one of the most widely used technologies in upper-limb myoelectric prostheses [1]. Surface electrodes detect electrical activity generated by muscle contractions.

Artificial intelligence and machine learning: Artificial intelligence (AI) and machine learning are increasingly important in the development of intelligent prosthetic systems. These technologies can analyze complex biological signals and identify patterns associated with specific movements. For example, a machine learning model can be trained to distinguish between different muscle activation patterns corresponding to hand opening, closing, or selected grasp types. After processing the signals, the system generates the appropriate control command.

Human–machine interfaces: Human–machine interfaces provide the communication link between the user and the prosthetic device. These interfaces may rely on muscle signals, mechanical inputs, implanted electrodes, or neural signals, depending on the design. Myoelectric interfaces are widely used because they can detect muscle activity without requiring direct access to the nervous system [2]. More advanced research investigates peripheral nerve interfaces and

other neural technologies that may enable more natural control and sensory restoration [3].

Adaptive movement control: Adaptive control allows a prosthesis to modify its behavior in response to movement patterns and environmental conditions. For example, a powered knee prosthesis may adjust its resistance according to walking speed or the phase of the gait cycle.

In upper-limb prostheses, control algorithms can regulate movement speed, motor activation, and grip force. Such capabilities may improve functional performance and reduce the need for repeated manual adjustments.

Applications of Smart Prostheses in Medicine and Rehabilitation

Smart prostheses have applications in rehabilitation medicine, biomedical engineering, assistive robotics, and clinical care. Their use is particularly important for people who have experienced limb loss as a result of trauma, disease, or other medical conditions. In upper-limb rehabilitation, myoelectric prostheses can support grasping, object manipulation, and selected daily activities [4]. In lower-limb rehabilitation, powered and sensor-controlled prostheses may assist walking and improve adaptation to different movement conditions.

Future Development Prospects

The future development of smart prostheses is closely connected with progress in artificial intelligence, robotics, materials science, sensor technology, and neuroengineering.

One important direction is the development of more robust AI algorithms capable of recognizing movement intentions despite changes in biological signals. Multimodal systems combining electromyography, inertial measurements, and force sensing may improve control reliability.

Conclusion

Smart prostheses represent a significant development in biomedical engineering, combining mechanical systems, electronic sensors, biological signal

processing, and intelligent control algorithms. Their capabilities extend beyond basic mechanical replacement by supporting movement recognition, adaptive operation, grip force regulation, and, in selected systems, sensory feedback [5].

Artificial intelligence and machine learning offer promising opportunities to improve prosthetic control and personalize device operation. Sensor integration and advances in human–machine interfaces may further enhance the interaction between users and artificial limbs.

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