Anbar Journal of Engineering Science (AJES) **Vol. 15 , No. 1 (2024) , pp. 131 ~ 154**
P-ISSN: 1997-9428 ; E-ISSN: 2705-7440 DOI: http://doi.org/10.37649/aengs.2024.152744.1097

University of Anbar

Anbar Journal of Engineering Science

journal homepage: https://ajes.uoanbar.edu.iq/

Smart Prosthetics Controller Types: Review

Ali Amer Ahmed Alrawi[a], Yousif Al Mashhadany[b], F.sh.khalifa[c], R. Badlishah Ahmad[d]

[a]*Electrical Engineering Department, Engineering College, University of Anbar, Anbar, Iraq*
Email: ali.amer@uoanbar.edu.iq , ORCID https://orcid.org/0000-0003-4204-6229
[b] *Electrical Engineering Department, Engineering College, University of Anbar, Anbar, Iraq*
Email: yousif.mohammed@uoanbar.edu.iq , ORCID https://orcid.org/0000-0003-3943-8395
[c]*Electrical Engineering Department, Engineering College, University of Anbar, Anbar, Iraq*
Email: F.sh.khalifa@uoanbar.edu.iq , ORCID https://orcid.org/0000-0001-7017-1794
[d]*Faculty of Electronics Engineering and Technology, Center of Excellence Advanced Computing Universiti Malaysia Perlis(UniMAP),*
Email: badli@unimap.edu.my, ORCID. http://orcid.org/0000-0002-4862-2728

PAPER INFO

Paper history
Received: 13/08/2024
Revised: 18/11/2024
Accepted: 10/12/2024

Keywords:
Limb, EMG, EEG,
ECG Electromyography
Prosthetics, Smart,
IOT, Intelligent Sensor,
Deep Learning. CAD CAM.

ABSTRACT

Advanced prosthetics are a crucial aspect of rehabilitation technology and are receiving increased attention globally. Approximately 2 million people require prosthetic limbs, presenting opportunities for enhancing their quality of life. State-of-the-art technologies such as realistic arms and myoelectric prostheses are gaining popularity. Progress in sensor technology, artificial intelligence, and materials has driven the field forward. Various types of controllers, including direct, pattern recognition, and proportional-derivative, have been developed. Integration of material science, computer science, artificial intelligence, and neurology has facilitated controller advancements. Techniques like targeted muscle reinnervation and Osseo integrated prostheses offer improved surgical options. Gesture recognition technologies and intelligent sensors are enhancing hand control. Future advancements will involve machine learning, artificial intelligence, and sensing techniques, while ethical concerns must be addressed. Advanced myoelectric prostheses, also known as myocontrolled or lower-limb micromod investigative prostheses, have a patient acceptance rate of 75% to 80%. However, while these methods offer advantages, there are also drawbacks. Integrating different types of controllers for these smart prostheses and enhancing the overall device's strength and robustness will have a significant impact. This discussion focuses on various types of smart prosthetic controllers, dividing muscle activity into extracellular myoelectric potential and EEG signals.

1. Introduction

Mobile (or active) prosthetics have revolutionized the prosthetic field to an extent concerning the innovative ability to address customer requirements and patterns of motion, making the prostheses much more efficient and convenient to use. The emergence of smart prosthetic controllers has given rise to various ethical questions such as

* Corresponding author: Ali Amer Ahmed Alrawi; ali.amer@uoanbar.edu.iq ; +964-7802825349

retention and sharing of data, consent and non-discrimination of persons who require such advanced limb prosthesis technology. Clinician-industry as well as clinician-academia partnerships have been instrumental in enhancing the capabilities and ergonomics of prosthetic products using the medical knowledge, academic research and technological inventions. However, one primary distinctive feature that defines smart prosthetics is the real-time interaction with the user's movement, making the process smoother than utilizing regular prosthetic instruments. This is especially so since the research is still ongoing and more developments are expected to be made in the future, aspects such as; Sensory feedback systems: Improved artificial intelligence: Prosthetic smarter interaction: connectivity among prosthetics and other devices. Artificial limbs, which makes patients who have undergone through operations, that lead to the loss of their limbs regain their mobility and independence. Such prostheses contain various controls incorporated in the limb's functionality, which is very crucial in determining the movements of the prosthetic limb. Some review articles that have been done previously in the field of control techniques for rehabilitation have provided useful information in the specific field, various control systems. However, a detailed analysis is needed especially based on the variety of controllers applicable to the concept of smart prostheses. Smart prosthetic controllers may be classified into two primary categories: Myo-electric control and direct neural control are the other two techniques. Myoelectric control systems use signals generated by the contraction of the muscles of the amputee or the user who wants to control the prosthetic limb. These systems generally employ sEMG electrodes placed on the amputee's residual limb to record the muscle contractions and translate it into the movements of the prosthesis. On the other hand, direct neural control interfaces create a straight link to the user's nervous system, usually through the application of implants or electrodes located on the surface of the brain that capture signals to control the prosthetic limb. The potential of this just emerging kind of control is based in its ability to provide a more natural and intuitive command over more sophisticated prostheses. Furthermore, it enhances precise and coordinated movements to ensure that the actions by the users can easily perform complex operations. Since the aim of this review article is to give an extensive survey on the multitude of controllers employed in smart prostheses. The text will give an outline of the principles as well as advantages and limitations of Myoelectric control as well as direct brain control systems. Additionally, it will look at the last advancements in controller design and technology such as the use of machine learning and adaptive control. Will discuss the benefits and the limitation of employing these controllers in the intelligent prostheses applications for instance improvement of functionality, unit user experience as well as a chance of enhancing the capability to gather sensory information. Controlling officers are required for directing the movements and the actions of the advanced static support equipment that enhances the usefulness and the degree of self-sufficiency since there is a greater call for such organs. The hypothesis of the review article will be broadly outlined in terms of the following questions: What are the basic tenets? Advantages and disadvantages that are connected with the two major types of controllers. Furthermore, it will assess the most emerging advancements and inventions falling under any of the above categories. In addition, considerate of the effects or pros and cons that the users have on these controllers in the actuality of intelligent prosthetics, including user satisfaction, comfort, and usability. This review article is planned to offer a critical analysis regarding all the kinds of controllers employed in smart prostheses. Its purpose is to reveal the achievements and challenges of this rapidly evolving field and the overall aspiration is to assist in the development of better and more efficient prostheses. Present day prostheses have also made a significant impact for such patients in as much as they are able to regain their mobility and be independent. In this recent past there has been a significant improvement in the kind of prosthetic limbs that are available in the market and these are referred to as smart prosthetics and these are artificial limbs endowed with varying controls. Modern day prosthetics have unarguably allowed amputees to regain functionality and be more independent by improving their quality of life. Only intended as a review article this manuscript will discuss the ideas, advantages and disadvantages of the two types of controllers and also explore new trends. The advancement and innovations of each and every one. In addition, we will look into the implications and its users' stand concerning the use of such controllers in smart prosthetics. In recent times, there has been a lot of developments in the prosthetic system or what many refer to as smart prosthetics which are more advanced prosthetics that have a range of controllers. Therefore, the goal of this review article emanates from the desire to deliver a systematic outlook on the controllers applied in smart prosthetics. The controllers in smart prostheses have the significant role in the enhancement of the functionality of the prostheses, the improvement of the user satisfaction, and the incorporation of the sensory signals. Also, these controllers are prerequisite to effectively control the movements and actions of intelligent prostheses so that users can perform operations with less effort and in a more efficient way.

1.1 The advancement of controller technology in prosthetics

Technology in prosthetics has grown rapidly in the last few years and some of today's smart prosthetics are complex prosthetic devices that provide for various controls. These controllers being myoelectric or mechanical have been designed with the objective of increasing functionality, improving the user interface and to incorporate sensory feedback. The technological improvement of the controller has been of great assistance in the development of smart prostheses that allow a user to regain his or her independence and somewhat feel normal. Another noteworthy advancement in controllers employed in smart prostheses is that while early controllers, which can be described as mechanically designed, have in fact evolved to today's myoelectric ones. These have revolutionary's prosthetics by providing the patients with lost limbs with an ability to regain functionality. Two primary kinds of controllers are typically used in the area of smart prosthetics: myoelectric and mechanical feedback that allows for the management of the proficiency level. Essentially, these two kinds of controllers are different in their concepts, advantages and limitations. Myoelectric controllers are based on measuring and identifying the electrical signals generated by the muscles of the remaining section of the limb. These are then applied in the command of motions of the artificial limb to achieve a more realistic as well as intuitive handling of the limb. Mechanical controllers on the other hand rely on mechanical systems and switches to detect and determine external pressures and movement hence make a sturdier and reliable interface for intelligent prostheses as indicated in the Fig 1. Consequently, the improvement of the controller technology in prosthetics is currently the result of many disciplines, such as material science, computer science, artificial intelligence, and neurology. Progress in developing steady and predictable prosthetic equipment, which can offer improved aesthetics, integration and the satisfaction of the patients [1] has direct impact on the learning and teaching of prosthetics and orthotics causing certain changes in the curriculum and technology.

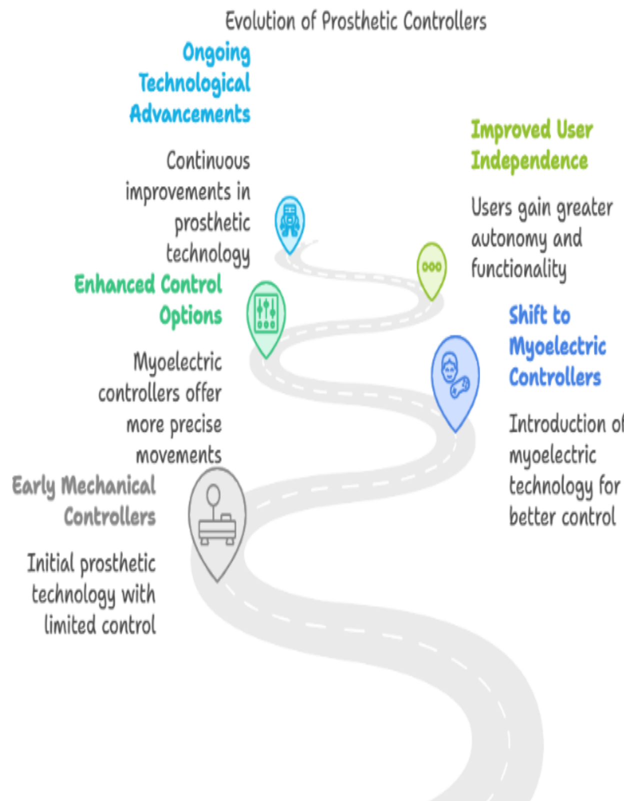

Figure 1. Comparing myoelectric and mechanical controllers in smart prosthetics.

To the survey, it is possible to state that there exist options in order to gain more control in many joints through prosthetic systems, assisted by surgery and technology developments [2,3]. Progress has however been made in the field of prosthetics, their design and motor control however the issue of sensory feedback remains a challenge [4]. Neuro prosthetic limbs may be effectively controlled using interfaces that connect to the peripheral nervous system [5]. Furthermore, progress in surgical methods and technology, such as targeted muscle reinnervation and Osseo integrated prostheses, provides optimism for the restoration of feeling and enhancement of prosthetic functioning [6].

With the use of flexible tactile sensors and technologies on robotics, scientists have been able to develop very ideal prosthetic units for human contacts [7]. One of the critical factors that should be controlled or monitored effectively is the impedance to ensure that the position to force relationship in the lower limb prosthesis is well controlled [8]. Also, deep learning and surface electromyography integration in gesture detection boost the prosthetic hand control systems [9]. There is more evidence that prostheses are using state of art manufacturing methods to devise prosthetics and Implants such as 3D bio printing [10]. Additionally, the creation of bionic limbs that attach directly to the bone, better prosthesis control through implanted sensors and complex algorithms, and the ability to provide sensory input through electrodes implanted in peripheral nerves are all helping to make bionic limbs that work very well [11].In conclusion, the controller technology development in prosthetics has been a synergy process that is connected with many fields from the materials science, surgical operations, sensors, and control systems. These are improvements that have made prosthetic devices easy to use, comfortable and attractive enhancing the lives of people who have undergone Limb loss.

Zhang et al. (2020) proposed a method that estimates the position change of multiple joints using the electromyography (EMG) signals. This approach makes it possible to operate the robotic hands because it estimates the various joint movements at the same time and in proportion. Dantas et al. (2019) proposed it in their study [12] using the deep learning movement intent decoders that were trained with dataset aggregation for controlling prosthetic limbs [13]. Lukyanenko et al. (2021) proposed a novel accurate and fast method for the control of a 4-DoF prosthetic hand. This method uses the synergy inspired linear interpolation to offer stable, simultaneous as well as proportional control [14]. The areas of sEMG signals for simultaneous and proportional control were categorized by Lin et al.

(2018) through the use of a method called sparse non-negative matrix factorization [15]. Hu and his co-authors proposed a method for decoding motion of the hand with myoelectric signals in online manner in 2020. The approach it holds involves labeling the data that is obtained [16]. Guo et al. (2021) introduced a new network known as the extended exposure convolutional memory network that effectively forecasts finger movements from surface electromyography signals. In line with Dwivedi et al. (2019)'s study [17], the proposed learning framework involves applying classic machine learning algorithms for decoding complex in-hand manipulation movements through EMG signals [18]. Ma et al. (2021) proposed a new and efficient way of getting the features in deep learning models in order to make continuous estimations of value [19]. Piazza et al. (2020) investigated a technique of operating a Trans radial prosthesis with potentially high DOF through the utilization of myoelectric signals [20]. Analyzing muscular models according to Hill's theory, winters (1990) also investigated the use of the theory in the sphere of systems engineering [21]. Pan et al. designed a myoelectric control system that embraced an ideal musculoskeletal model for an artwork interface that can be deployed by different people [22]. Shin et al. (2009) also described a myokinetic arm model that used for estimating the joint torque and stiffness by EMG data during posture holding [23]. Stapornchaisit et al. (2019) investigated linear regression model as well as independent component analysis to predict the finger angle with arrangements of an array EMG system [47]. In 2016, Crouch and Huang elaborated a basic model of the human hand that is controlled by the electromyogram and which might be used for real-time Myo control of prosthetics [25]. Musculoskeletal model is controlled by the excitation originated from muscle synergies and focused on the movements of the hand and wrist by Zhao et al. (2022) [26].

Table 1. Studies on Control of Prosthetic Limbs and Robotic Hands."

Ref.	Authors	Methods
12	Zhang et al.	Devised a technique to calculate the movement of multiple joints based on electromyography (EMG) data, enabling the operation of robotic hands by predicting the joint movements in a simultaneous and proportionate manner
13	Dantas et al.	Proposed the use of deep learning movement intent decoders trained via dataset.

Ref.	Authors	Methods
14	Lukyanenko et al.	Introduced a reliable and efficient approach for controlling a 4-DoF prosthetic hand using synergy-inspired linear interpolation for stable, simultaneous, and proportional control.
15	Lin et al.	Devised a technique for effectively extracting fundamental functions for the concurrent and proportional management of myoelectric signals using sparse non-negative matrix factorization
16	Hu et al.	Introduced a technique for decoding continuous hand motion using myoelectric signals in real-time, involving automated data tagging
17	Guo et al.	Presented a novel extended exposure convolutional memory network accurately predicting finger movements based on surface electromyography inputs.
18	Dwivedi et al.	movements based on electromyography (EMG) signals.'),
19	Ma et al.,	Introduced a new and effective technique for extracting features in deep learning models to estimate values continuously.
20	Piazza et al.	Assessed a method of controlling a trans radial prosthesis with many degrees of freedom using myoelectric signals.
21	Winters	Examined muscular models based on Hill's theory, focusing on their application within the field of systems engineering.'),
22	Pan et al.	Introduced a myoelectric control system utilizing a universal musculoskeletal model for a neural-machine interface.
23	Shin et al.	Presented a myokinetic arm model for estimating joint torque and stiffness based on EMG data while maintaining a posture.
24	Stapornchaisit et al	Used a linear regression model analysis from an array EMG system.
25	Crouch and Huang	Introduced a simplified electromyogram-driven musculoskeletal hand model for real-time control of prosthetics.
26	'Zhao et al.	Presented a musculoskeletal model controlled by excitations resulting from muscle synergies, specifically for hand and wrist motions

1.2 Comparative evaluation and examination of current solutions

This review study has the objective of reviewing the numerous sorts of controller implemented in the smart prostheses along with the extensive elucidation of the functionality, advantages, limitations, and applications related to the controller. The paper will describe the advancement of controller technology in prosthetics and investigate how enhancement has advanced utilization and synergy with sensation. Further, we will analyze the current state of solutions in the industry, critically look at the performance of myoelectric and mechanical controllers. This makes its advancement bring battery and enlargement of the functional, safety, accuracy, operability, adaptability and other characteristics of electromechanical products. The advances have been made especially in the field of controlling the smart prosthetics in the recent past. It has improved the operational efficiency, security, and convenience of IDs in intelligent prosthetics, combining the asset into a person's daily life and restoring more independence and mobility to the individual. Thus, this review study seeks to present a systemic and comprehensive outlook into the varieties of the controllers employed to smart prostheses. In smart prostheses, this paper will discuss about the ideas of myoelectric and mechanical controller; pros and cons of these two controllers will also be included. Furthermore, the advancement and innovations in controllers in smart prostheses will also be discussed together with the improvement of functionality and ease of use in its operation. Thus, to assess and analyses modern approaches in the field of prosthetic technology it could be useful to obtain certain knowledge from a range of sources that overview various aspects of enhancements in prosthetics. In their works [27,28] Mereu and collaborators underline the progress made in the control techniques of upper limb prosthesis reporting the ability to manage several joints of the prosthesis with complex systems. This can be considered as a great progress in the field of prosthetics and in the motor control technology. In a paper by Bates (2013), the focus is on the developments in the morphology of the prosthetic devices and the process of rehabilitation for people with upper extremity limb amputation. The author singles out TMR, which improves the control and sensation of prosthetic limbs, and regenerative interfaces as recent innovations. Also, Pyo et al. [29] discuss the development of flexible tactile sensors for human-robot systems that may enhance sensory feedback for prosthetic applications. This has the positive possibility that with the advancement in technology prosthetic limbs will be operated more naturally and automatically. Kunrath et al. [30] look at the application of zirconia with CAD CAM technology in manufacturing of prosthetic parts with a shift towards more personalized prosthetics. Nizamis et al. [30,31] study EMG, brain interfaces, and body power supply as the control interfaces of the prosthesis. They stress the importance of the applied concept to ensure primary integration between the user and the prosthetic device. Furthermore, Pradhan et al., [32] as regard the connectivity of intelligent sensors in the IoT environment in robotic context. These sensors offer good ways of providing feedback in prosthetic systems, and so enhance the functionality and control; it underlines how material science has to advance as a way of helping the creation of safe prostheses. In this respect, similar to Boretti, A. [33] deal with technology of 3D bio printing and its application in production of individual prostheses and implants. It shows that prosthetic designs can be made to be more personalized thus developed to suit the specific patient that needs it. Finally, analyzing and evaluating the modern solutions in prosthetic technology, it is possible to note the diverse development of the control techniques, and incorporation of sensitization, material science, personalized approach and usage of the intelligent technologies. These advancements together contribute to the improvements of the prosthetic devices into more effectual, agreeable, and user-centric.

Table 2. Overview of Authors and Methods in Smart Prostheses Controller Technology Review

Ref.	Authors	Method
[27]	Mereu et al.	Emphasize the advancement of control techniques in upper-limb prosthesis, specifically focusing on the intuitive management of numerous joints via sophisticated systems.
[28]	Bates	Explores advancements in prosthesis design and rehabilitation for individuals who have lost upper extremity limbs, highlighting innovations such as targeted muscle reinnervation and regenerative interfaces.
[29]	Pyo et al.	Examine the advancements in flexible tactile sensors for systems that interact with humans, which may improve the sensory feedback in prosthetic devices.
[30]	Kunrath et al.	Examine the use of zirconia in conjunction with CAD/CAM technology for the production of prosthetic components, highlighting a transition towards individualized and tailored prosthetic solutions.

[32]	Pradhan et al.	Explore the integration of intelligent sensors in robotic settings supported by the Internet of Things (IoT).
[33]	Boretti, A.	Explore the use of 3D bioprinting technology in creating personalized prostheses and implants, demonstrating the possibility of creating highly customized prosthetic designs tailored to individual patients.

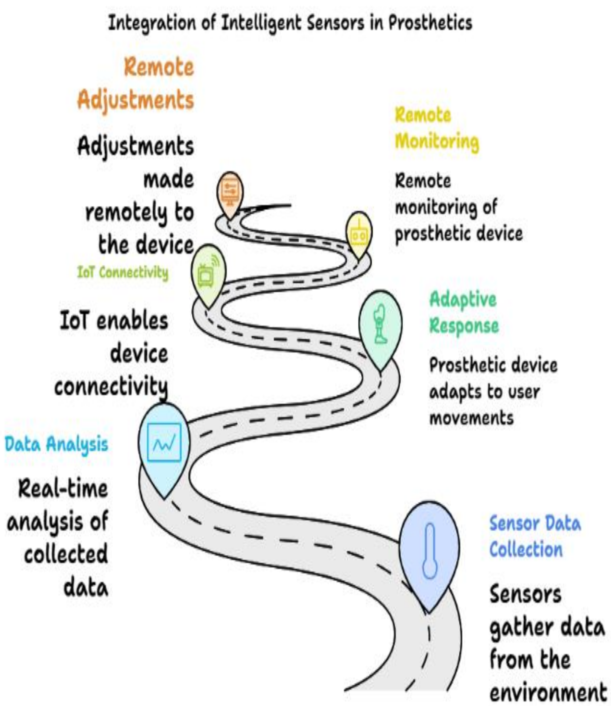

Figure 2. Integration of Intelligent Sensors in Prosthetics

1.3 An introduction to smart prosthetic controllers

Advanced prostheses have changed the face of assistive technology through enhancing movement in the affected limb, or perhaps the totally loss of the limb through the provision of enhanced mobility and ability to perform normal tasks that some patients using these devices find easy to do. The state of the art prosthetics has refined control systems that enable the movements of the prosthetic limb to be controlled down to a mere fraction of the normal limb's functioning. In this review study, an attempt is made to discuss and analyze numerous types of controllers incorporated in smart prostheses. In this discussion, we will examine the fundamental concepts, benefits, and constraints associated with two primary categories of controllers: The two categories of muscle contractions are myoelectric and mechanical. It is also possible to discuss how the advancements in prosthetic controller technology has enhanced the functional capabilities and patient perceptible feedback. Furthermore, there will be comparative analysis and evaluation of existing solutions on the market that will entail a critical look into myoelectric and mechanical controllers. Also, we will investigate the impact of future technologies in the development of control algorithms for smart prostheses including; machine learning and artificial intelligence. Intuitively, one can mention that the subject area of smart prosthetics has also evolved significantly in recent years due to the rapid advancement in the field. This has led to the design of better and efficient controllers to enhance the intelligent prostheses thus making them more efficient, safe and easy to use. Integration of smart sensing and Actuation devices along with the Networking and Computing technologies has significantly impacted the gait rehabilitation. These enhancements have allowed for the development of highly integrated smart rehabilitation systems that would be able to track physical and neurological disorders without violating the patient's privacy, diagnose and identify complicated gait patterns, real time decision making, biofeedback, control of assistive robots among other things. Concerning the controllers of smart prosthetics, it is worth noting the reflection of state-of-art developments in enhancing the quality of prosthetic devices and their performance. Smart sensors have the versatility that can be put to practical uses including the development of artificial electronic skin for use in robots as well as in prosthetic devices. As stated by Boretti, A. [34], this may also improve the degree of tactile feedback and control signals. In the field of nanomedicine achievements are made towards the development of smart technologies for optimizing the performance of living organisms. Such systems can influence the development of controllers in the prosthetic devices that include sophisticated features [35]. The control of prosthetics by means of peripheral nerve, muscle or brain signals means that the tech is smart and the growth towards even more actionable interfaces is continuing apace [36]. Integrating intelligent sensors into Internet of Things (IoT)-enabled robotic settings offers effective ways to receive information for prosthetic systems, leading to improved control and performance [37]. Improvements in control methods have made it easier to use many joints in complex prosthetic systems. This shows how artificial intelligence and computer science are combined in smart prosthetic controllers [38]. Gesture recognition technologies are essential for enhancing the quality of life for individuals with amputations by allowing them to manipulate prosthetic hands in a natural manner [39]. Smart materials play a crucial role in improving the functioning and control of prosthetic devices in terms of both space and time [40]. Moreover, the use of intelligent hydrogels in tissue engineering offers possibilities for prosthetic components that are sensitive and adaptive [41]. Smart prosthetic controllers, which integrate smart sensors, artificial intelligence, and smart materials, have the potential to transform the field of prosthetics by combining sophisticated technology. These advancements strive to optimize the user experience, boost functionality, and provide more intuitive control interfaces for those who have lost limbs.

Table 3. Methods in Advancements of Smart Prosthetic Controllers.

Ref.	Authors	Method
[34]	Boretti, A. et al.	Discusses how the integration of smart sensors might enhance sensory feedback and control mechanisms, as mentioned ..
[35]	Datta, S et. al.	Highlights progress in the field of nanomedicine resulting in the creation of intelligent systems enhancing the functioning of living organisms, potentially impacting the design of prosthetic controllers with advanced capabilities.
[36]	J. Li and K. Kataoka	Explores how smart technology enables users to manipulate prostheses using peripheral nerve, muscle, or brain input, signifying a transition towards more intuitive and user-centered control interfaces.
[37]	A. Baumann et. al.	Examines the integration of intelligent sensors into Internet of Things (IoT)-enabled robotic settings to receive information for prosthetic systems, leading to improved control and performance.
Ref.	**Authors**	**Method**
[39]	F. Mereu et. al.	Highlights the importance of gesture recognition technologies for enhancing the quality of life for individuals with amputations by enabling natural manipulation of prosthetic hands.
[40]	W. Li, et. al.	Discusses the crucial role of smart materials in improving the functioning and control of prosthetic devices, particularly in terms of both space and time.
[41]	M. Pinteala et. al.	Explores the use of intelligent hydrogels in tissue engineering, offering possibilities for prosthetic components that are sensitive and adaptive.

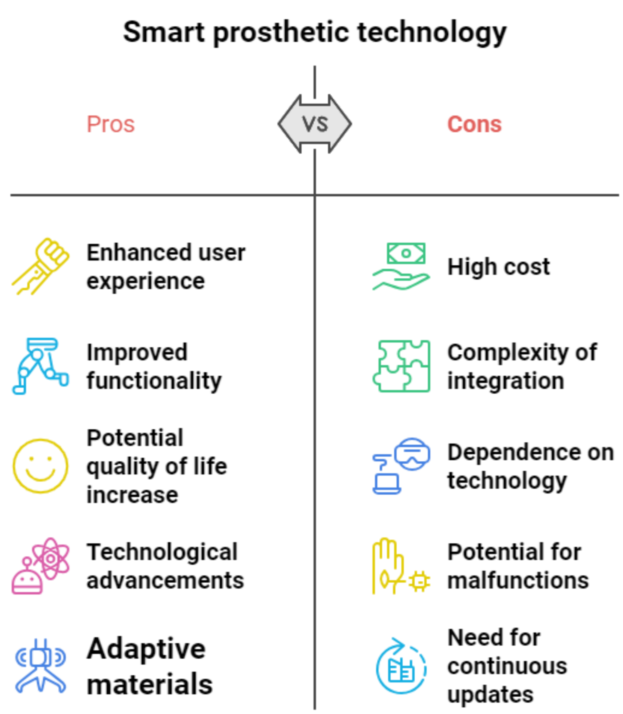

Figure 3. Smart prosthetic technology

2. Emerging Developments in Prosthetic Control Systems

developments in the process of creating prosthetic control systems are expected to shape the advancement of smart prosthetics. One is that machine learning and artificial intelligence frameworks have been integrated with prosthetic control. These novel technologies are capable of significantly improving the realism, speed and adaptability of smart prostheses, thus offering a better control based on the user's goals and patterns. The kinesthesia and prosthetic control should also improve due to the latest sensors such as IMU and tactile sensing. If this happens then the carrier between the user and the artificial limb decreases in size.

Further, due to the continual advancement in technology, by continuously miniaturizing prosthetic devices and integrating their components, control systems shall be made lighter and more efficient in meeting the user's comfort and needs. At the same time, the emergence of secure and stable wireless communication protocols will enhance the integration of prosthetic device and external interfaces and enable immediate protocols change as well as fully customized settings for the user. A new trend that can be observed today is the connection of prosthetic control systems with virtual and augmented reality.

By realizing this integration, it is possible to create for the users training environment which might help them with the process of adaption of the prosthesis and ability to control them. Furthermore, it can yield a lot of information for the development of the appropriate rehabilitation plan. As for the technological advancements in the control systems of prosthetics in the future, there are fundamental expectations that stipulate this area's significant progress considering the application of state-of-the-art technologies. The investigations of Nizamis et al. and Mereu et al. [42] also draws attention to the use of developing the info communication technologies based on the creation of the systems of the several levels that can be integrated, and it is possible to create the mixed systems.

These solutions can have an outcome to enhance the control of prosthetic systems through heightened simplicity. The incorporation of brain-computer interfaces or BCIs, as suggested in [43], is another prospect that can facets the elderly and older people's quality of life since it provides inventive applications that can be implemented with minimal technical monitoring. Some of the outcomes in limb prosthetics have been noted in [44], and it is evident that more research can be done in order to enhance the control of prosthetic limbs.

In addition, it is expected that pressure sensor systems, as provided in reference [45], will advance to meet the strict performance for comfortable and properly fitting prosthetic sockets. In [46], practicable control techniques are an application of gesture recognition technology that are believed to enhance clinical use of prosthetic control systems. As noted in [47], AI incorporation in smart prosthetic controllers and some level of smart sensors should be useful. This integration will enable the users to control prostheses with several varieties of peripheral nerve, muscle or brain signals.

In addition, various changes are being portrayed currently in the area of soft-tissue prosthetics for the design of prostheses with better functionality, which has been mentioned in reference [48]: There are possibilities that algorithms for determination of the gait phase described in [49] will be further developed, that is why it is possible future improved functioning and better control of prosthetic systems with the help of new mechanisms and powerful motors. It also poses that technology in the production of composite materials, such as ceramics used in implant-prosthetic parts [50], will contribute toward the production of long-lasting and harmonious interacting with living things prosthetic appliances.

Future innovations to control prosthetic are assumed to be based on such advanced technologies such as BCIs, neural interfaces, smart sensors and gestures. The transmission of such integrations will make the prosthetic solutions more compatible, sensitive and centered on the user.

Table 4. Methods in Advancements of Prosthetic Control Systems.

Ref.	Authors	Method
[42]	Z. Liu, et al.	Emphasize the possibility of combining different technologies to create hybrid solutions, aiming to improve the control of prosthetic systems and make them more intuitive.
[43]	Nizamis et al	Mentions the potential benefits of integrating brain-computer interfaces (BCIs) to improve the quality of life for older people and elderly patients by offering creative applications with less technical supervision.
[44]	Mereu et al.	Discusses the progress made in brain interfaces, showing potential for future research focused on improving the control of prosthetic limbs.
[45]	A. Belkacem et. al.	Anticipates progress in pressure sensor systems to fulfill rigorous criteria for measuring both comfort and fit in prosthetic sockets.
[46]	Tariq, et. al.	Expects gesture recognition technology to significantly improve the clinical application of prosthetic control systems.
[47]	S. Ko, et. al.	Indicates that the integration of artificial intelligence and smart sensors in smart prosthetic controllers will allow users to operate prostheses using various types of inputs, such as peripheral nerve, muscle, or brain signals.
[48]	W. Li, et. al.	Highlights the significant transformation in prosthetic design due to cutting-edge technology such as 3D imaging, modeling, and printing, particularly in the field of soft-tissue prosthetics.
[49]	A. Baumann et. al.	Discusses advancements in gait phase detection algorithms, which may lead to improved functioning and enhanced control of prosthetic systems in the future by incorporating innovative mechanisms and powerful motors.
[50]	R. Cruz, et. al.	Expects advances in making complex materials, such as ceramic composites used in implant-prosthetic components, to make prosthetic devices last longer and work better with living things.

According in Figure 4 it can provides a clear indication of the strategies that are most often mentioned in the given list of references. The information presented here might help in understanding the popularity and importance of different techniques in prosthetic control systems, considering the available literature. The best practices outlined in this document provide a framework for understanding the most effective strategies in prosthetic control systems. By focusing on user-centric design, adaptive technologies, and continuous feedback, developers can create prosthetic devices that significantly enhance the quality of life for users. As the field continues to evolve, staying informed about these best practices will be crucial for advancing prosthetic technology and improving user outcomes.

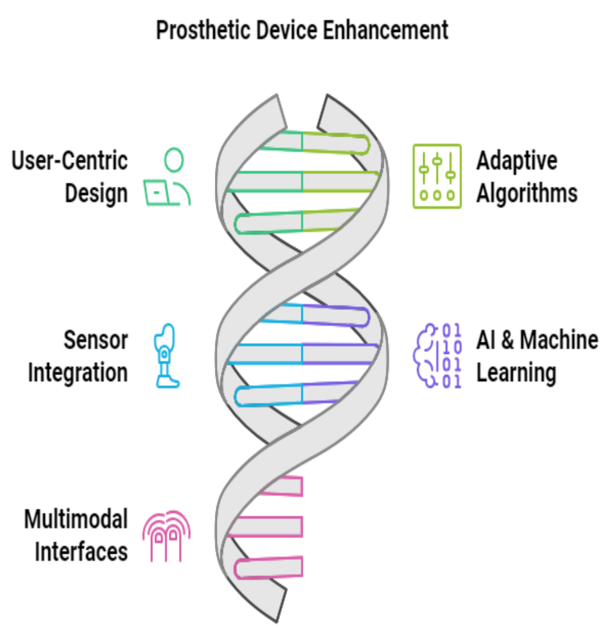

Figure 4. Prosthetic Device Enhancemen

2.1 Advancements in Prosthetic Control Systems

Thus, prosthetic control systems are occupying the leading positions in enhancing the functionality and usage of prosthetic devices with the help of innovation. Stating the facts like Artificial intelligence, block chain, and technologically advanced materials can revolutionize the prosthetic control system to a whole new level. In this way, through the application of such as microfluidics technology, it is viable to develop sophisticated lab on chip devices that possess the most well-functioning detection systems. As claimed by [51], these devices can be improving the control systems of prosthetic devices. In addition, e-Health application that combines blockchain and artificial intelligence opens up additional opportunities for the safe processing of data in prosthetic control systems [52]. It also means that with the help of IoT and robotics possibilities of creating adequate physical environment to support active aging can be developed. This, in turn, may help advance prosthetic control interfaces [53]. However, advancement in soft tissue prosthetics experienced through collaboration with clinician, academician, and industries has more prospects to enhance the functionality of prosthetic control systems [54]. Promising methods for improving prosthetic control relate to later developments in the area of volume and temperature in interfaces [55]. Again, developing diagnostic sensors for checking the pressure inside the abdomen proves the fact that the wireless sensing systems can be helpful in making the prosthetic control feedback mechanisms better [56]. In the future, it is expected that with the help of robotic technologies used in specific neurological rehabilitation, partly new approaches and technical synergies that can have a major impact on prosthetic control systems [57]. Moreover, using modern materials including hydrogels based on cellulose for the purpose of providing a constant drug release is capable of having a positive outcome on further elaboration of biocompatible elements for prosthetic parts [58]. Finally, the control systems on prosthetics are yet at the precipice of marked advancement through the integration of contemporary gadgetry and joint research as well as high-ende materials. This will, in turn, mean that technologies for prosthetics will become more natural, adaptive, and congruent with the user’s requirements.

Table 5. Prosthetic Control Systems

Ref.	Authors	Method
[51]	H. Vu, et. al.	Discusses the potential of devices to enhance the control mechanisms of prosthetic devices.
[52]	M. Kunrath et. al.	Highlights the integration of blockchain and artificial intelligence in e-health for safe and efficient handling of data in prosthetic control systems.
[53]	Panchal et al.	Explores opportunities presented by the emergence of the Internet of Things (IoT) and robotics in developing a physical environment
[54]	P. Tagde, et. al.	Discusses progress in soft-tissue prosthetics achieved through partnerships among clinicians, academia, and industry, which has the potential to improve the functionalities of prosthetic control systems.
[55]	Pradhan, et. al.	Examines advancements in volume and temperature control techniques in prosthetic interfaces, suggesting potential clinical uses for enhanced prosthetic control.
[56]	Powell, et. al.	Describes the creation of diagnostic sensors to check pressure inside the abdomen, indicating the use of wireless sensing systems to improve prosthetic control feedback mechanisms.
[57]	Safari, et. al.	Predicts the use of robotic technologies in specific neurological rehabilitation to provide new approaches and technical collaborations that might greatly influence prosthetic control systems in the future.
[58]	Liao, C	Discusses the incorporation of sophisticated materials, such as hydrogels based on cellulose, for continuous medication administration, potentially leading to progress in the development of biocompatible materials for prosthetic components.

The output will include Figure3, which will show a bar chart with the following characteristics: Each bar is labeled with the corresponding author's related method name, displayed above the bar.

- "Optimize the control mechanisms" for H. Vu
- M. Kunrath is researching the combination of blockchain and AI. - Panchal is studying the use of IoT and robots in promoting active aging. - P. Tagde's research focuses on soft-tissue prosthetics.
- Pradhan is investigating volume and temperature management.
- Powell's research focuses on wireless sensing systems. - Safari's research is centered on robotic technologies in rehabilitation. - Liao's area of expertise is in sophisticated materials used in prosthetics.

These methods encompass a range of topics, such as the integration of brain-computer interfaces (BCIs), advancements in soft-tissue prosthetics, utilization of gesture recognition technology, incorporation of artificial intelligence (AI) and smart sensors, and other related areas.

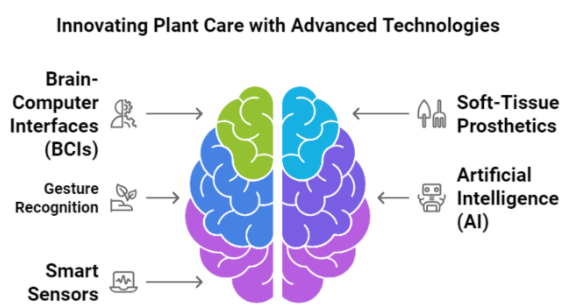

Figure 5. Advancing Healthcare with Innovative Technologies

2.3 Combining Machine Learning and Artificial Intelligence

The use of machine learning as well as its relation to artificial intelligence algorithms is a very influential factor in prosthetic control systems. These high-level technologies are capable of learning from the operations by the user and modify the control system to make more natural prosthetic limb motions. Computerized approaches of artificial intelligence may complement the interaction quality and adaptability of smart prostheses by identifying user's intention and movements. This results to a more personal and useful experience. If we want to analyses the integration of machine learning and artificial intelligence in prosthetic control systems, some information could be gained from such sources that explore use of these technologies in the sphere of healthcare and other related fields. There is a detailed description by Khan et al. [59] about the applications of artificial intelligence in the light of COVID-19 pandemic to show the feasibility of machine learning and deep learning for the healthcare sectors. This reference underscores the fluidity of approach in applying artificial intelligence to complex health care problems which might be applied to prosthetic control systems. Further, the study done by Iqbal et al. [60] aims at identifying the applicability of artificial intelligence, and machine learning in cancer detection particularly on the given contribution in individualized therapy. This reference also underscore the extent of AI and ML in the health sector which may be utilized to enhance the prosthetic control for users' satisfaction. Furthermore, the paper by Kapadia et al. [61] looks at the review of clinical use and effectiveness of intelligent systems within dentistry and maxillofacial radiology as a source that helps to shed light into the development made by artificial intelligence and deep learning. Here is the citation regarding the ability of such artificial intelligence technologies to radically revolutionize diagnostic processes potentially applicable to prosthetic control systems, to increase their effectiveness and applicability. In conclusion, the integration of machine learning and artificial intelligence into the prosthetic control systems has the capacity for enhancement in the functions, use and adaptability. Thus prolonging the time which these artificial limbs would require or extending these devices to cater up to the needs of the patients using newest advancements of artificial intelligence (AI) used in healthcare to improve and give the best out of the situations.

3.Cutting-edge Sensor Technologies

Advanced sensor technologies, such as inertial measurement units and touch sensors, are being used to pioneer advancements in prosthetic control systems. These sensors greatly improve sensory feedback and proprioceptive control in smart prostheses, enabling a smoother interface between the user and the prosthetic limb. By enhancing sensory input, users may achieve an elevated level of control and awareness, resulting in a more instinctive and effortless use of their intelligent prosthesis. In [62] have produced artificial sensory skin for robotic and prosthetic applications using innovative materials and technologies. Pressure sensor systems for evaluating the comfort and fit of prosthetic sockets have encountered technological difficulties throughout their progress [63]. Advanced, adaptable, and slim EMG sensors may be directly included into prosthetic liners to improve comfort and address skin contact problems caused by changes in limb volume [64]. Considerable advancements have been achieved in enhancing the efficiency and capabilities of on-skin electrodes for monitoring electrophysiological activity and facilitating interactions between humans and machines in the last ten years [65]. Integrating sensors into prosthetic sockets or using ferromagnetic targets in a socket liner has shown potential for improving prosthetic fitting and adjustments in the future [66].

3.1 Reducing the size and combining the components

Advancements in the downsizing and integration of components in prosthetic devices have resulted in the development of control systems that are lighter and more efficient. This phenomenon encourages enhanced comfort and usefulness for individuals, as prosthetic devices grow less conspicuous and more closely mimic the natural motion and sensation of a biological limb. Moreover, the integration of downsizing and better technologies enhance the concept of the various control interfaces as compact and ergonomic as possible. Wu, H. et al Advanced Materials (2021), in Reference Defining the progress in flexible tactile sensors for human-interactive systems. They major in artificial sensory skin which is a critical aspect in robotics as well as in prosthetics. The reference, in this case, points out the necessity of the inclusion of novel materials and the use of advanced technologies in the creation of sensors, signal processing, and transmission. Of all these advancements, size reduction and integration of components in prosthetic control systems are very crucial. The study conducted by KO Et Al. [68] in Sensors (2021) investigates pressure sensor systems used in prosthetic sockets for Tran's femoral amputees during walking. The research elucidates the difficulties and factors to be taken into account when designing sensors, shedding light on the constraints in terms of space and the problems linked to the sensitivity of pressure sensors. These aspects are rather important in order to achieve the primary goal of down scaling and in addition, integrating sensor elements into prosthetics. The paper, "Significance of sensory feedback in upper-limb prostheses" authored by Sensinger and Došen is a review paper published in Frontiers in Neuroscience (2020). The reference points to low-impedance end-effectors and extra feedback loops on prosthesis for enhanced performance and control through the use of advanced sensor solutions.

3.2 Effortless and uninterrupted connection, along with customized configurations.

Advancements in the wireless communication have enabled constant communication between prosthetic systems and external peripherals. This kind of thinking and advancement allows for instant changes and specific settings with little limitations and variation in the use of the prosthetic control systems according to the individual who wants it done. The capability to quickly correct and fine-tune the control variables enhances the subscribers' satisfaction of the solution and facilitates a more profound sense of self-sufficiency.

4. Integration with Virtual Reality and Augmented Reality

A growing trend in prosthetic control systems involves the use of virtual reality and augmented reality technology. This convergence provides users with immersive training settings, which help them adjust to and master prosthesis control. Additionally, it generates significant data that may be used for individualized rehabilitation programs. Virtual Reality (VR) and Augmented Reality (AR) technologies provide users with a simulated platform to improve their ability to manage prostheses. This is done via interactive and captivating scenarios, which eventually aid in their rehabilitation and boost their confidence in utilizing advanced prosthetics in real-life situations. Integration of the VR and AR technology in the prosthetic control system offers a revolutionary approach towards bettering the experience, rehabilitation, and getting a training. Through the use of immersive technology, customers can choose their configurations and connect greatly with them with less effort which makes a change in the prosthetics industry. In line with this, the simultaneous interaction with objects through VR produced during rehabilitation enhances motor recovery in diseases such as cerebral palsy, Parkinson's disease, or stroke according to Amirthalingam et al. These VR therapists have the potential to enhance the motor learning and the functional rehabilitation by mimicking real life actions and movements. Augmented reality (AR) is a technology that superimposes virtual aspects onto the actual world, enabling smooth interaction with digital information that is incorporated into the physical environment [71]. Augmented reality (AR) applications in prosthetic control systems provide immediate feedback, customized configurations, and user-friendly interfaces for efficient device operation. The integration of VR and AR results in MR possibilities that allow virtual and actual objects to be involved in the application and give the viewer an opportunity to interact simultaneously. Magnetic resonance (MR) could be employed for adapting individualized configurations in prosthetic control; the interfaces and feedback could be modified according to user's needs. Virtual reality (VR) and augmented reality (AR) devices that are seamlessly integrated with prosthetic control systems allow data to flow instantly, making prosthetic devices more flexible and faster [72].

Table 6. Integration Virtual Reality and Augmented Reality

Ref.	Authors	Method
[70]	Amirtha lingam et al.	Interactive experiences using virtual reality (VR) for motor function improvement in rehabilitation.
[71]	J. Sensing er et. al	Augmented reality (AR) applications for immediate feedback and user-friendly interfaces.
[72]	S. Ko, F. et. al	Integration of VR and AR devices with prosthetic control systems for flexible and faster operation.

By integrating sophisticated sensor technologies and customized configurations, virtual reality and augmented reality may provide a complete method for prosthesis rehabilitation and training, enhancing user results and comfort. Finally, the use of virtual reality and augmented reality technology in prosthetic control systems appears to have the possibility of enhancing the client satisfaction and make it possible to have customized settings and ensured signal flow. Augmented realities present opportunities of enhancing the change in prosthetic rehabilitation, training and usefulness for the clients that have lost limbs.

5. Control strategies inspired by biological systems

Bio-inspired control schemes are also being used in the enhancement of sophisticated control of smart prosthetic limbs. Scientists and engineers are striving to apply precise mathematical concepts and methods of a controlling system that mimics the human muscular and nervous structures, or, in other words, attempting to emulate the natural movement control of the human body. Due to these bio-inspired control mechanisms the intelligent prostheses offer more natural control and smooth movement of the prosthesis limb, thus making the user feel more assured as the limb is an extension of their own body. The control techniques of Robots and prostheses have advanced immensely through the use of biomimicry to enhance functionality and efficiency. In Bio mimetics (2020), Ellery explores bio-methods for robotic strategies and application in space remnant collection. The relevance of the bio-inspired control system in the case of added flexibility in robotics is also underlined in the study. Also, by considering the effect of biological reflexes as well as the feedback control loops, Baud et al. Dr engage the Journal of Neuro engineering and Rehabilitation (2021) to investigate control algorithms of lower-limb exoskeletons. Such as feedback or 'reflexes', which are used in this bio-inspired model to generate activation signals for virtual muscles. Depending on the information about the position of the joints and the interaction of the lower extremities with the supporting surface, these signals are produced. On this aspect, the model establishes how biology is incorporated into control systems. In their article published in Advanced Science (2021), Zhou et al. [74] focus on soft grippers inspired by biology that apply impactive grasping. They highlight the present development in soft gripper which has been designed based on biological systems. This reference emphasizes about the necessity of utilizing the bio inspired designs for the purpose of developing a versatile soft gripper. Finally, bio-inspired control systems in robotics and prosthetics engage concepts from nature advanced to enhance control mechanism, versatility and viability. Thus, these methodologies offer new paths for improvements of the performance characteristics of robotics and prosthesis by emulating biological processes and behavior.

5.1 Improved Cognitive Interface

And muscle activity. This allows the person to correctly and efficiently perform activities with the prosthetic limb in place. T The advances in cognitive interfaces further describe the impact on the design of advanced control systems of smart prostheses. Scientists are also studying bci and emg techniques to decode neural signals as cognitive interfaces are capable of revolutionizing the interaction between the users and their smart prostheses scholarly research primary data.

5.2 Adaptive Learning & Personalization

Control applications of prosthetics have developed learning algorithms so that the prosthetic can alter and adapt to the specific movements and ways in which any user maybe comfortable with. Smart prosthetics are characterized in that they are capable of learning processes which occur permanently. This results in the possibility to define the user's movements, to regulate control parameters in real time, and to offer relatively high degree of individual settings for comfort and usability. The ability to adapt also plays a certain role in increasing the acceptability of users and optimization of the satisfaction rate with the control of smart prosthetic limbs. Thus, following the information indicated in the above references, the incorporation of virtual reality (VR) and augmented reality (AR) to control systems of prosthesis will significantly enhance adaptive learning and personalization for users. Referring to the considered definitions, immersive technologies offer new approaches toward education, skill development, and therapy in various fields including medicine and health care. To this end, the study done by Moro et al. [75] published in Anatomical Sciences Education (2021) focused on the enhancement of virtual reality (VR) and augmented reality (AR) interfaces for boosting the performance of medical and scientific learners in physiology and anatomy tests. These technologies have had indications regarding their effectiveness of enhancing learning experiences and scores, thus dispositions of their capacities in adaptive learning and other customized education settings. Furthermore, the study conducted by Barteit et al. [76] carrying out a systematic review of head-mounted devices, augmented, mixed and virtual reality for medical education in JMIR Serious Games (2021). These AR, MR, and VR technologies offer the students rich experiences which may be useful in teaching complex medical information proving the usefulness of developing custom environments. The systematic review by Jain et al. [77] published in the Journal of Medical Internet Research in 2020 aims at syntheses of the available body of literature that focuses on the effectiveness of virtual reality in nursing courses. The findings of the study indicate that the virtual reality environment with more interactions is more effective for information acquisition supporting the role of VR in healthcare learning with an accent on the adaptive learning approaches. Finally, the integration of VR/AR into prosthetic control systems could mean that each prosthetic user would be able to have his or her own approach to learning how to use the prosthetics and hence make education, training as well as prosthetics rehabilitation easier for those who have lost limbs. In the area of prosthetics, immersive technologies extend the possibilities for the creation of specific environment and flexible learning environments.

6. Collaboration between humans and machines

The advancement in the cooperation between human and machines in prosthetic control systems are opening up a favorable environment for the constructive relationship between the users and their intelligent prostheses. The control of smart prosthetics and its integration with the natural movement of the user is made easy, and swift since they consist of simple user interfaces and timely responses. This cumulatively aims toward enhancing the user's perceived control and sense of self-regulating his/her intelligent prosthesis, consequently resulting into an enhancement of perceived experience.

7. Understanding and responding to the environment and adapting accordingly.

The future developments in prosthetic control systems are also oriented towards the perception of environment and its changes. Some of the advanced prosthetic devices need peripherals in the form of environmental sensors and high algorithms to provide the prosthetic the ability to mimic the user's environments in different scenarios and thus perform optimally depending on what the user is doing. Users may effectively negotiate different situations, such as busy metropolitan areas or rough terrain, using a prosthetic limb that can adapt to unique needs. Neurological integration refers to the process of connecting and coordinating different parts of the nervous system. Brain-computer interfaces are devices that allow direct communication between the brain and a computer or other external device. An area of prosthetic controller research that is particularly captivating is the merging of neurological signals with brain-computer interfaces. Advancements in fields of neurotechnology and neurorehabilitation have allowed to interact with a user's neurological signals in a more definitive manner to control smart prosthetic limbs more naturally. This integration of neurobiology is likely to enhance the issue of control, level of dexterity and the rate at which the prosthetics is being operated to achieve the intended goals and actions by the user thus minimizing on the discrepancy that exists between the user's thoughts and the functional limb. Neutralization and BCIs have significant contributions on the advances of healthcare especially on the aspects of neurorehabilitation and cognitive enhancement. Combining of both the Virtual Reality (VR) and Augmented Reality (AR) with brain computer interfaces (BCIs) provides innovative solutions to cope with settings and modify learning in prosthetic control systems. More concretely, the article that addresses the present study is an article available in Brain Sciences by Georgiev et al (2021) and with the title Virtual reality in neurorehabilitation and cognitive outcomes'. Therefore, the paper establishes the possible use of state-of-art BCIs in enhancing the existing neurorehabilitation by applying BCIs to control several robotized interfaces related to cortical electricity. Furthermore, the systematic review of barriers and future directions of BCIs in neurorehabilitation by Simon et al. , in Frontiers in Neuroscience (2021). The review focuses on Non-invasive BCIs as an analysis tool to evaluate the acquired signals and convert them into movement promising new technical approaches in motor rehabilitation. Also, the study conducted by Yang et al [80], in Biomed Research International (2021) aims at exploring the use of Brain-Computer Interface (BCI) on stroke neurorehabilitation. The information, presented in the article under discussion is devoted to the communication of the stroke patients with the help of BCIs and their environment utilizing the signals. This technology offers a novel way of enabling persons with a stroke to engage with the environment while in the process of rehabilitation. Thus, the implementation of BCIs, VR, AR, and neurorehab technologies could help to bring a positive prospect for developing the processes of learning, setting, and motor retraining for persons with neurological injuries, such as stroke and brain trauma.

8. Machine learning and adaptive control algorithms

In the future development of prosthetic controllers, more machine learning methods and adaptive control systems will be used. Advanced prosthetic limbs collect data and adjust themselves to improve the control methods based on the device's own analysis of the user condition and his interactions with the surroundings. This makes the method flexible and improves customized and fine-grained control environments that consider changes in the level of skills and preferences as time elapses. Machine learning and adaptive control algorithms have the ability to revolutionize several forms of industries such as health, robotic, and prosthetics. If the prosthetic devices incorporate machine learning algorithms then the device may be able to learn, have separate settings that are unique to the user's personality and may be able to come up with control mechanisms that have not been implemented before. Advanced Healthcare Materials (2021) contains an article of Zhang et al. on applying machine learning to amplify noninvasive biosensors in the healthcare domain. The reference describes challenges and opportunities referring to biosensors with the help of machine learning capability to learn and adapt in order to monitor and diagnose in real-life and out-of-clinic-context settings. Sarker [82] has published an article in the journal SN Computer Science in 2021 where the author elaborated on several classifications of MLAs and their real-world applications. The test also encompasses many types of learning, namely supervised, unsupervised, semi-supervised, and reinforcement learning pointing out to the scope of the machine learning methodologies. The paper by Nurcahyani & Lee [86] on Sensors (2021): An analysis on the incorporation of machine learning in the resource allocation strategy in vehicular networks. The reference deals with the possibility of the allocation of the resources in the network through the application of the machine learning methods employing the resource allocation systems. In term of review conclusion, it is conclusive that the application of machine learning and adaptive control algorithms in the prosthetic control system presents various innovative approaches to meet individual specification, learning adaptability and system performance enhancement. These technologies have the potential of bringing significant changes to prosthetic devices by offering tailored solutions for persons with limbs' deficiency. Sensory Feedback Augmentation means the process of increasing the input data that is received by a person's senses, particularly in a real-time context. Subsequent controllers of prosthetic system in the future will probably research high-level tactile feedback augmentation to mimic touch and proprioception of the user. Recent technological developments related to haptic feedback, touch screens and sensory substitution intends to improve the user's sense of touch so that the user would be able to feel and interact with surroundings through the change of artificial limb. These augmentations have the capability of increasing the user's feel of space and control of small phase shifts that will in turn enrich their day-to-day activities and communication. From the given references, incorporating machine learning algorithms and adaptive control techniques might help in integrating sensory feedback into prosthetic control systems. These technologies can enable advances in prosthetic function, control capabilities and anthropomorphicty of prosthetics. The article entitled 'Adaptation of a Wearable Tactile Feedback System for Patients with Bilateral Peripheral Neuropathy' by Handelzalts et al. [87] published in Frontiers in Neurorobotics in 2021 describes how a sensory feedback technology worn on the skin that was originally designed to assist amputees is to be altered for patients with peripheral neuropathy. Specifically, the following study revolves around analgesic effect of gabapentin in patients with bilateral peripheral neuropathy. This adaptation to learning helps to show the effectiveness of machine learning in improving the sensory feedback systems so that the levels of functionality improve. Moreover, the study done by Halperin et al. [88] in the European Journal of Neuroscience in 2020 shifts the focus on new output devices that help to sense self-movement.

9. The topic of discussion is the concept of miniaturization and its use in wearable technology.

People have predicted that in the future, this sector's progress will be made possible by miniaturization of prosthetic controls, and wearables. The supposed outcome is the increased comfort, confidentiality and the possibilities of movement provided to the users, by applying miniaturized control interfaces which might be incorporated to the wearable devices or garments Users. These interfaces also enable users to have full control in their operations of the smart prosthetic limbs. This trend reflects the developments in prosthetics aimed at designing the devices that can be easily incorporated into the user's life and do not affect his/her movements or looks. citing the sources given, the addition of wearable and smaller BCIs to neurorehabilitation and adaptive learning may substantially affect the prosthetic control systems as well as the personalised settings. These technologies which are still in the developmental phase offer technologic advances for better usability, therapy, and assistive devices. Another technology identified in the study by Rivas, F et al. [89] in Disability and Rehabilitation Assistive Technology (2020) in collaboration with assistive technologies is the Brain-Computer Interfaces (BCIs) that help in control of prosthetic limbs and motor rehabilitation. The benefits of BCIs are described with regard to augmentative and alternative communication, mobility, and cognitive rehabilitation, proving that BCIs are versatile in individual cases. Further, the review study by Ramadan, R. A. [90] in Sensors (2021) maps the advancements and challenges in Brain-Computer Interfaces (BCIs), while emphasizing the field's interdisciplinary nature. BCIs for adjusted environments and flexible studying are signified by the evaluation offering individual solutions for the users with neurological issues.

10. Obstacles in the design of intelligent prosthetic controllers

There are great opportunities, as well as challenges, existing in the design of smart prosthetic controllers. These challenges need to be resolved to realize the benefits of intelligent prosthetic limb control to the maximum extent possible and have a tangible positive impact on the users' lives. Stating these cited references, it is possible to note the following difficulties in designing the smart prosthetic controllers: The solutions for the given difficulties can be the integration of miniaturization and wearable technologies; the implementation of machine learning algorithms and practical usage of the adaptive control scheme. Post that, the above mentioned technologies appear to offer methods for increasing the productivity, flexibility, and haptic feel of smart prosthetic surfaces. Nonetheless, Fitzgerald and colleagues [91] published a research in Sensors in 2024 concerning the strategies for controlling transradial prostheses pertaining to the remaining muscles' actions and proprioceptive sensations. Each of the methods outlined in the research emphasizes difficulties associated with them and proprioceptive information which is vital for the control of the artificial limbs; more so the high dexterity prosthetic hands. Also, the article Segura [92] dedicated to the issue of lower limb prosthetic interfaces, elaborated for the Prosthetics and Orthotics International in 2024; the work reveals the challenges related to the design of artificial extremities and implantation of the prosthesis. When it comes to touch, the interaction between people and prosthesis is said to be diverse, and more emphasis is placed on the need to tackle issues associated with prosthesis. Thus, in conclusion, it can be said that size reduction, the use of wearable technology, machine learning algorithms, the use of control algorithms such as adaptive control help quite effectively in solving the problem in developing controllers for smart prosthetics. : The foregoing integration enhances usability, viability, as well as flexibility of the prosthetic devices for the user.

Integration of humans with machines and enhancement of human capabilities via augmentation. The integration of neurotechnological interfaces with smart prosthetic devices leads to a seamless merger of human and machine capabilities. Such intricate prosthetic controllers exceed the typical possibility of interaction between a human and a machine since these devices interact with the target's neurons. This allows the prosthetic limb to be as much a part of the user as is any other limb. Moreover, all of the proposed algorithms acquire the user's specific pattern of movement, preconditions, and interaction with the environment, which means that the synergy of human-oriented tasks and computer-driven responses is achieved. Thus, this enhanced capacity empowers people, to possess better command, precision, and adaptability and alter their means of engaging confidently and proficiently in many activities and tasks. As it can be observed from the cited references, it is then quite possible to pry the said енногmities in the design of improved smart prosthetic controllers and the wearable technologies, machine learning algorithms, and adaptions on the control architectures. These technologies contain potential that smart prosthetic controls could possibly become more functional, more flexible, and offer better interaction to the end-users. Sensors (2020) has an article called "Control Methods for Transradial Prostheses Based on Remnant Muscle Activity and Proprioceptive Feedback [93], it talks about how remnant muscle activity and its relationship with proprioceptive feedback can be used to control transradial prostheses. The research emphasizes the difficulties linked to each method and their connection with proprioceptive input, which is essential for instinctive manipulation of prosthetic devices, particularly advanced prosthetic hands. In addition, the article titled "Lower Limb Prosthetic Interfaces: Prosthetic and orthopedic devices & artificial limbs implantation is the area of interest and the article with the heading 'Challenges in Designing Artificial Limbs and Prosthetic Implantation' published in the Prosthetics and Orthotics International is a perception of the various hurdles seen when designing artificial limbs and implanting prosthetic devices [94].

11. Ethical considerations & accessibility

As the intelligent prosthetic controllers become more complex and integrated in everyday life, it is beneficial to consider their moral effects and to ensure equal opportunities for the controllers' users [95]. In order to prevent possible infringements on users' rights and their ability for self-determination, the ethical regulations concerning the use of the neural interface and of AI run algorithms employed in prosthetics have to be closely examined. These rules include data always being private, people only receive information they agreed to receive, and everyone is given equal opportunities to access the information. In addition, endeavors. When addressing the issue of ethics in the design of wearable technology and smart prosthetic controls, it is possible to suggest the following points that may be important in the design for vulnerable populations: Issues of data protection and privacy, as well as the use of technology that is accessible to as many people as possible, irrespective of other conditions that a person may have. Some of the ethical concerns include protection of data of the user, privacy and getting consent for collecting and using data. Empirical findings indicate that more should be done to protect the collected data by wearables since the user data privacy and subsequently data security are paramount [96]. Accessibility to the product is an important factor and will hence be of importance when it comes to designing wearable technology and smart prosthetic controls for individuals with different abilities. These are the factors such as; interfaces, with control and feedback facilities [97]. This also includes considering the possibility of the given technology becoming integrated with the kind of devices that disabled people use.

References

[1] Reinhard, J., Urban, P., Bell, S., Carpenter, D., & Sagoo, M. S. (2024). Automatic data-driven design and 3D printing of custom ocular prostheses. Nature Communications, 15(1), 1360.

[2] S. Spaulding, S. Kheng, S. Kapp, & C. Harte, "Education in prosthetic and orthotic training", Prosthetics and Orthotics International, vol. 44, no. 6, p. 416-426, 2020. https://doi.org/10.1177/0309364620968644

[3] F. Mereu, F. Leone, C. Gentile, F. Cordella, E. Gruppioni, & L. Zollo, "Control strategies and performance assessment of upper-limb tmr prostheses: a review", Sensors, vol. 21, no. 6, p. 1953, 2021. https://doi.org/10.3390/s21061953

[4] A. Karczewski, A. Dingle, & S. Poore, "The need to work arm in arm: calling for collaboration in delivering neuroprosthetic limb replacements", Frontiers in Neurorobotics, vol. 15, 2021. https://doi.org/10.3389/fnbot.2021.711028

[5] K. Yildiz, A. Shin, & K. Kaufman, "Interfaces with the peripheral nervous system for the control of a neuroprosthetic limb: a review", Journal of Neuroengineering and Rehabilitation, vol. 17, no. 1, 2020. https://doi.org/10.1186/s12984-020-00667-5

[6] T. Bates, "Technological advances in prosthesis design and rehabilitation following upper extremity limb loss", Current Reviews in Musculoskeletal Medicine, vol. 13, no. 4, p. 485-493, 2020. https://doi.org/10.1007/s12178-020-09656-6

[7] L. Zhu. Et.al. Intelligent Biosensors for Healthcare 5.0. In Federated Learning and AI for Healthcare 5.0 (pp. 61-77). IGI Global. 2024

[8] K. Nizamis, A. Athanasiou, S. Almpani, C. Dimitrousis, & A. Astaras, "Converging robotic technologies in targeted neural rehabilitation: a review of emerging solutions and challenges", Sensors, vol. 21, no. 6, p. 2084, 2021. https://doi.org/10.3390/s21062084

[9] W. Li, P. Shi, & H. Yu, "Gesture recognition using surface electromyography and deep learning for prostheses hand: state-of-the-art, challenges, and future", Frontiers in Neuroscience, vol. 15, 2021. https://doi.org/10.3389/fnins.2021.621885

[10] C. Tan, K. Liang, Z. Ngo, C. Dube, & C. Lim, "Application of 3d bioprinting technologies to the management and treatment of diabetic foot ulcers", Biomedicines, vol. 8, no. 10, p. 441, 2020. https://doi.org/10.3390/biomedicines8100441

[11] D. Farina, I. Vujaklija, R. Brånemark, A. Bull, H. Dietl, B. Gramlichet al., "Toward higher-performance bionic limbs for wider clinical use", Nature Biomedical Engineering, vol. 7, no. 4, p. 473-485, 2021. https://doi.org/10.1038/s41551-021-00732-x

[12] Li, K., Zhang, J., Wang, L., Zhang, M., Li, J., & Bao, S. (2020). A review of the key technologies for sEMG-based human-robot interaction systems. Biomedical Signal Processing and Control, 62, 102074.

[13] M. Xia, C. Chen, X. Sheng and X. Zhu, "On Detecting the Invariant Neural Drive to Muscles during Repeated Hand Motions: A Preliminary Study," 2021 27th International

Conference on Mechatronics and Machine Vision in Practice (M2VIP), Shanghai, China, 2021, pp. 192-196, doi: 10.1109/M2VIP49856.2021.9665089.

[14] H. Dantas. Et.al. Deep learning movement intent decoders trained with dataset aggregation for prosthetic limb control. IEEE Transactions on Biomedical Engineering, 66(11), 3192-3203. 2019.

[15] P. Lukyanenko. Stable, simultaneous and proportional 4-DoF prosthetic hand control via synergy-inspired linear interpolation: a case series. Journal of NeuroEngineering and Rehabilitation, 18, 1-15. 2019

[16] C. Lin. Et.qi. Robust extraction of basis functions for simultaneous and proportional myoelectric control via sparse non-negative matrix factorization. Journal of neural engineering, 15(2), 026017. 2018

[17] Hu, X., Zeng, H., Chen, D., Zhu, J., & Song, A. (2020, May). Real-time continuous hand motion myoelectric decoding by automated data labeling. In 2020 IEEE International Conference on Robotics and Automation (ICRA) (pp. 6951-6957). IEEE.

[18] W. Guo. Et.al. Long exposure convolutional memory network for accurate estimation of finger kinematics from surface electromyographic signals. Journal of Neural Engineering, 18(2), 026027. 2021

[19] R. V. Godoy. On emg based dexterous robotic telemanipulation: Assessing machine learning techniques, feature extraction methods, and shared control schemes. IEEE Access, 10, 99661-99674. 2022

[20] A. R. Zangene. Et.al. An efficient attention-driven deep neural network approach for continuous estimation of knee joint kinematics via sEMG signals during running. Biomedical Signal Processing and Control, 86, 105103. 2023

[21] C. Piazza. Evaluation of a simultaneous myoelectric control strategy for a multi-DoF transradial prosthesis. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 28(10), 2286-2295. 2020.

[22] Z. Chen. Et.al. A review of myoelectric control for prosthetic hand manipulation. Biomimetics, 8(3), 328. 2023.

[23] D. Shin. et. al. A myokinetic arm model for estimating joint torque and stiffness from EMG signals during maintained posture. Journal of neurophysiology, 101(1), 387-401. 2009

[24] S. Stapornchaisit, et.al. Finger angle estimation from array EMG system using linear regression model with independent component analysis. Frontiers in neurorobotics, 13, 75. 2019

[25] D. L. Crouch, H. Huang, Lumped-parameter electromyogram-driven musculoskeletal hand model: A potential platform for real-time prosthesis control. Journal of biomechanics, 49(16), 3901-3907. 2016.

[26] J.Zhao. et.al. A musculoskeletal model driven by muscle synergy-derived excitations for hand and wrist movements. Journal of Neural Engineering, 19(1), 016027. 2022

[27] F. Mereu, F. Leone, C. Gentile, F. Cordella, E. Gruppioni, & L. Zollo, "Control strategies and performance assessment of upper-limb tmr prostheses: a review", Sensors, vol. 21, no. 6, p. 1953, 2021. https://doi.org/10.3390/s21061953

[28] J. Lee. Et.ql. Recent Advances in Smart Tactile Sensory Systems with Brain-Inspired Neural Networks. Advanced Intelligent Systems, 2300631. 2024.

[29] S. Pyo, J. Lee, K. Bae, S. Sim, & J. Kim, "Recent progress in flexible tactile sensors for human-interactive systems: from sensors to advanced applications", Advanced Materials, vol. 33, no. 47, 2021. https://doi.org/10.1002/adma.202005902

[30] M. Kunrath, S. Gupta, F. Lorusso, A. Scarano, & S. Noumbissi, "Oral tissue interactions and cellular response to zirconia implant-prosthetic components: a critical review", Materials, vol. 14, no. 11, p. 2825, 2021. https://doi.org/10.3390/ma14112825

[31] K. Nizamis, A. Athanasiou, S. Almpani, C. Dimitrousis, & A. Astaras, "Converging robotic technologies in targeted neural rehabilitation:

a review of emerging solutions and challenges", Sensors, vol. 21, no. 6, p. 2084, 2021. https://doi.org/10.3390/s21062084

[32] B. Pradhan, D. Bharti, S. Chakravarty, S. Ray, V. Voinova, A. Бонарцевet al., "Internet of things and robotics in transforming current-day healthcare services", Journal of Healthcare Engineering, vol. 2021, p. 1-15, 2021. https://doi.org/10.1155/2021/9999504

[33] G. Cervino, M. Cicciù, A. Herford, A. Germanà, & L. Fiorillo, "Biological and chemo-physical features of denture resins", Materials, vol. 13, no. 15, p. 3350, 2020. https://doi.org/10.3390/ma13153350

[34] A. Boretti. A perspective on 3D printing in the medical field. Annals of 3D Printed Medicine, 13, 100138. 2024.

[35] S. Datta, , & R. Barua. 3D Printing in Modern Healthcare: An Overview of Materials, Methods, Applications, and Challenges. *Emerging Technologies for Health Literacy and Medical Practice*, 132-152. 2024

[36] J. Li and K. Kataoka, "Chemo-physical strategies to advance the in vivo functionality of targeted nanomedicine: the next generation", Journal of the American Chemical Society, vol. 143, no. 2, p. 538-559, 2020. https://doi.org/10.1021/jacs.0c09029

[37] A. Baumann, C. O'Neill, M. Owens, S. Weber, S. Sivan, R. D'Amicoet al., "Fda public workshop: orthopaedic sensing, measuring, and advanced reporting technology (smart) devices", Journal of Orthopaedic Research®, vol. 39, no. 1, p. 22-29, 2020. https://doi.org/10.1002/jor.24833

[38] B. Pradhan, D. Bharti, S. Chakravarty, S. Ray, V. Voinova, A. Бонарцевet al., "Internet of things and robotics in transforming current-day healthcare services", Journal of Healthcare Engineering, vol. 2021, p. 1-15, 2021. https://doi.org/10.1155/2021/9999504

[39] F. Mereu, F. Leone, C. Gentile, F. Cordella, E. Gruppioni, & L. Zollo, "Control strategies and performance assessment of upper-limb tmr prostheses: a review", Sensors, vol. 21, no. 6, p. 1953, 2021. https://doi.org/10.3390/s21061953

[40] W. Li, P. Shi, & H. Yu, "Gesture recognition using surface electromyography and deep learning for prostheses hand: state-of-the-art, challenges, and future", Frontiers in Neuroscience, vol. 15, 2021. https://doi.org/10.3389/fnins.2021.621885

[41] M. Pinteala, M. Abadie, & R. Rusu, "Smart supra- and macro-molecular tools for biomedical applications", Materials, vol. 13, no. 15, p. 3343, 2020. https://doi.org/10.3390/ma13153343

[42] Z. Liu, J. Liu, X. Cui, X. Wang, L. Zhang, & P. Tang, "Recent advances on magnetic sensitive hydrogels in tissue engineering", Frontiers in Chemistry, vol. 8, 2020. https://doi.org/10.3389/fchem.2020.00124

[43] K. Nizamis, A. Athanasiou, S. Almpani, C. Dimitrousis, & A. Astaras, "Converging robotic technologies in targeted neural rehabilitation: a review of emerging solutions and challenges", Sensors, vol. 21, no. 6, p. 2084, 2021. https://doi.org/10.3390/s21062084

[44] F. Mereu, F. Leone, C. Gentile, F. Cordella, E. Gruppioni, & L. Zollo, "Control strategies and performance assessment of upper-limb tmr prostheses: a review", Sensors, vol. 21, no. 6, p. 1953, 2021. https://doi.org/10.3390/s21061953

[45] A. Belkacem, N. Jamil, J. Palmer, S. Ouhbi, & C. Chen, "Brain computer interfaces for improving the quality of life of older adults and elderly patients", Frontiers in Neuroscience, vol. 14, 2020. https://doi.org/10.3389/fnins.2020.00692

[46] M. Tariq, & S. B. Ismail. Deep learning in public health: Comparative predictive models for COVID-19 case forecasting. Plos one, 19(3), e0294289. 2024.

[47] S. Ko, F. Asplund, & B. Zeybek, "A scoping review of pressure measurements in prosthetic sockets of transfemoral amputees during ambulation: key considerations for sensor design", Sensors, vol. 21, no. 15, p.

5016, 2021. https://doi.org/10.3390/s21155016

[48] W. Li, P. Shi, & H. Yu, "Gesture recognition using surface electromyography and deep learning for prostheses hand: state-of-the-art, challenges, and future", Frontiers in Neuroscience, vol. 15, 2021. https://doi.org/10.3389/fnins.2021.621885

[49] A. Baumann, C. O'Neill, M. Owens, S. Weber, S. Sivan, R. D'Amicoet al., "Fda public workshop: orthopaedic sensing, measuring, and advanced reporting technology (smart) devices", Journal of Orthopaedic Research®, vol. 39, no. 1, p. 22-29, 2020. https://doi.org/10.1002/jor.24833

[50] R. Cruz, M. Ross, S. Powell, & M. Woodruff, "Advancements in soft-tissue prosthetics part a: the art of imitating life", Frontiers in Bioengineering and Biotechnology, vol. 8, 2020. https://doi.org/10.3389/fbioe.2020.00121

[51] H. Vu, D. Dong, H. Cao, T. Verstraten, D. Lefeber, B. Vanderborghtet al., "A review of gait phase detection algorithms for lower limb prostheses", Sensors, vol. 20, no. 14, p. 3972, 2020. https://doi.org/10.3390/s20143972

[52] M. Kunrath, S. Gupta, F. Lorusso, A. Scarano, & S. Noumbissi, "Oral tissue interactions and cellular response to zirconia implant-prosthetic components: a critical review", Materials, vol. 14, no. 11, p. 2825, 2021. https://doi.org/10.3390/ma14112825

[53] H. Panchal, N. Kent, A. Knox, & L. Harris, "Microfluidics in haemostasis: a review", Molecules, vol. 25, no. 4, p. 833, 2020. https://doi.org/10.3390/molecules25040833

[54] P. Tagde, S. Tagde, T. Bhattacharya, P. Tagde, H. Chopra, R. Akteret al., "Blockchain and artificial intelligence technology in e-health", Environmental Science and Pollution Research, vol. 28, no. 38, p. 52810-52831, 2021. https://doi.org/10.1007/s11356-021-16223-0

[55] B. Pradhan, D. Bharti, S. Chakravarty, S. Ray, V. Voinova, A. Бонарцевет al., "Internet of things and robotics in transforming current-day healthcare services", Journal of Healthcare Engineering, vol. 2021, p. 1-15, 2021. https://doi.org/10.1155/2021/9999504

[56] A. Powell, R. Cruz, M. Ross, & M. Woodruff, "Past, present, and future of soft-tissue prosthetics: advanced polymers and advanced manufacturing", Advanced Materials, vol. 32, no. 42, 2020. https://doi.org/10.1002/adma.202001122

[57] R. Safari, "Lower limb prosthetic interfaces", Prosthetics and Orthotics International, vol. 44, no. 6, p. 384-401, 2020. https://doi.org/10.1177/0309364620969226

[58] C. Liao, C. Cheng, C. Chen, Y. Wang, H. Chiu, C. Penget al., "Systematic review of diagnostic sensors for intra-abdominal pressure monitoring", Sensors, vol. 21, no. 14, p. 4824, 2021. https://doi.org/10.3390/s21144824

[59] M. Khan, M. Mehran, Z. Haq, Z. Ullah, S. Naqvi, M. Ihsanet al., "Applications of artificial intelligence in covid-19 pandemic: a comprehensive review", Expert Systems With Applications, vol. 185, p. 115695, 2021. https://doi.org/10.1016/j.eswa.2021.115695

[60] M. Iqbal, Z. Javed, H. Sadia, I. Qureshi, A. Irshad, R. Ahmedet al., "Clinical applications of artificial intelligence and machine learning in cancer diagnosis: looking into the future", Cancer Cell International, vol. 21, no. 1, 2021. https://doi.org/10.1186/s12935-021-01981-1

[61] K. Nizamis, A. Athanasiou, S. Almpani, C. Dimitrousis, & A. Astaras, "Converging robotic technologies in targeted neural rehabilitation: a review of emerging solutions and challenges", Sensors, vol. 21, no. 6, p. 2084, 2021. https://doi.org/10.3390/s21062084

[62] D. Ciolacu, R. Nicu, & F. Ciolacu, "Cellulose-based hydrogels as sustained drug-delivery systems", Materials, vol. 13, no. 22, p. 5270, 2020. https://doi.org/10.3390/ma13225270

[63] M. Kapadia, M. Desai, & R. Parikh, "Fractures in the framework: limitations of classification systems inpsychiatry", Dialogues in Clinical Neuroscience, vol. 22, no. 1, p. 17-26, 2020.

[64] Li, H., Hang, Z., Song, K., Han, F., Liu, Z., & Tian, Q. (2024). Flexible and stretchable implantable devices for peripheral neuromuscular electrophysiology. Nanoscale.

[65] S. Ko, F. Asplund, & B. Zeybek, "A scoping review of pressure measurements in prosthetic sockets of transfemoral amputees during ambulation: key considerations for sensor design", Sensors, vol. 21, no. 15, p. 5016, 2021.

[66] A. Fleming, N. Stafford, S. Huang, X. Hu, D. Ferris, & H. Huang, "Myoelectric control of robotic lower limb prostheses: a review of electromyography interfaces, control paradigms, challenges and future directions", Journal of Neural Engineering, vol. 18, no. 4, p. 041004, 2021.

[67] H. Wu, G. Yang, K. Zhu, S. Liu, W. Guo, Z. Jianget al., "Materials, devices, and systems of on-skin electrodes for electrophysiological monitoring and human–machine interfaces", Advanced Science, vol. 8, no. 2, 2020. https://doi.org/10.1002/advs.202001938

[68] M. Hewitt, D. Smith, J. Heckman, & P. Pasquina, "Covid-19: a catalyst for change in virtual health care utilization for persons with limb loss", Pm&r, vol. 13, no. 6, p. 637-646, 2021.

[69] K. Zhang. et.al. Machine learning-reinforced noninvasive biosensors for healthcare. Advanced Healthcare Materials, 10(17), 2100734. 2021.

[70] J. Amirthalingam, G. Paidi, K. Alshowaikh, A. Jayarathna, D. Salibindla, K. Karpinska-Leydieret al., "Virtual reality intervention to help improve motor function in patients undergoing rehabilitation for cerebral palsy, parkinson’s disease, or stroke: a systematic review of randomized controlled trials", Cureus, 2021.

[71] J. Sensinger and S. Došen, "A review of sensory feedback in upper-limb prostheses from the perspective of human motor control", Frontiers in Neuroscience, vol. 14, 2020.

[72] S. Ko, F. Asplund, & B. Zeybek, "A scoping review of pressure measurements in prosthetic sockets of transfemoral amputees during ambulation: key considerations for sensor design", Sensors, vol. 21, no. 15, p. 5016, 2021.

[73] T. Zhan, K. Yin, J. Xiong, Z. He, & S. Wu, "Augmented reality and virtual reality displays: perspectives and challenges", Iscience, vol. 23, no. 8, p. 101397, 2020.

[74] U. Mohamad, M. Ahmad, Y. Benferdia, A. Shapi'i, & M. Bajuri, "An overview of ontologies in virtual reality-based training for healthcare domain", Frontiers in Medicine, vol. 8, 2021.

[75] A. Ellery, "Tutorial review of bio-inspired approaches to robotic manipulation for space debris salvage", Biomimetics, vol. 5, no. 2, p. 19, 2020.

[76] R. Baud, A. Manzoori, A. Ijspeert, & M. Bouri, "Review of control strategies for lower-limb exoskeletons to assist gait", Journal of Neuroengineering and Rehabilitation, vol. 18, no. 1, 2021.

[77] L. Zhou, L. Ren, C. You, S. Niu, Z. Han, & L. Ren, "Bio-inspired soft grippers based on impactive gripping", Advanced Science, vol. 8, no. 9, 2021.

[78] C. Moro, J. Birt, Z. Štromberga, C. Phelps, J. Clark, P. Glasziouet al., "Virtual and augmented reality enhancements to medical and science student physiology and anatomy test performance: a systematic review and meta-analysis", Anatomical Sciences Education, vol. 14, no. 3, p. 368-376, 2021.

[79] S. Barteit, L. Lanfermann, T. Bärnighausen, F. Neuhann, & C. Beiersmann, "Augmented, mixed, and virtual reality-based head-mounted devices for medical education: systematic review", Jmir Serious Games, vol. 9, no. 3, p. e29080, 2021. https://doi.org/10.2196/29080

[80] R. Jain, R. Carneiro, A. Vasilica, W. Chia, A. Souza, J. Wellingtonet al., "The impact of the covid-19 pandemic on global neurosurgical education: a systematic review", Neurosurgical Review, vol. 45, no. 2, p. 1101-1110, 2021.

https://doi.org/10.1007/s10143-021-01664-5

[81] D. Georgiev, I. Georgieva, Z. Gong, V. Nanjappan, & G. Georgiev, "Virtual reality for neurorehabilitation and cognitive enhancement", Brain Sciences, vol. 11, no. 2, p. 221, 2021. https://doi.org/10.3390/brainsci11020221

[82] C. Simon, D. Bolton, N. Kennedy, S. Soekadar, & K. Ruddy, "Challenges and opportunities for the future of brain-computer interface in neurorehabilitation", Frontiers in Neuroscience, vol. 15, 2021. https://doi.org/10.3389/fnins.2021.699428

[83] S. Yang, R. Li, H. Li, K. Xu, Y. Shi, Q. Wanget al., "Exploring the use of brain-computer interfaces in stroke neurorehabilitation", Biomed Research International, vol. 2021, p. 1-11, 2021. https://doi.org/10.1155/2021/9967348

[84] K. Zhang, J. Wang, T. Liu, Y. Luo, X. Loh, & X. Chen, "Machine learning-reinforced noninvasive biosensors for healthcare", Advanced Healthcare Materials, vol. 10, no. 17, 2021. https://doi.org/10.1002/adhm.202100734

[85] I. Sarker, "Machine learning: algorithms, real-world applications and research directions", Sn Computer Science, vol. 2, no. 3, 2021. https://doi.org/10.1007/s42979-021-00592-x

[86] I. Nurcahyani and J. Lee, "Role of machine learning in resource allocation strategy over vehicular networks: a survey", Sensors, vol. 21, no. 19, p. 6542, 2021. https://doi.org/10.3390/s21196542

[87] S. Handelzalts, G. Ballardini, C. Avraham, M. Pagano, M. Casadio, & I. Nisky, "Integrating tactile feedback technologies into home-based telerehabilitation: opportunities and challenges in light of covid-19 pandemic", Frontiers in Neurorobotics, vol. 15, 2021. https://doi.org/10.3389/fnbot.2021.617636

[88] O. Halperin, S. Israeli-Korn, S. Yakubovich, S. Hassin-Baer, & A. Zaidel, "Self-motion perception in parkinson's disease", European Journal of Neuroscience, vol. 53, no. 7, p. 2376-2387, 2020. https://doi.org/10.1111/ejn.14716

[89] F. Rivas. Architectural Proposal for Low-Cost Brain–Computer Interfaces with ROS Systems for the Control of Robotic Arms in Autonomous Wheelchairs. Electronics, 13(6), 1013. 2024

[90] R. A. Ramadan. Deciphering the Mind: Advanced Neuroimaging Techniques and Cognitive State Decoding in Brain-Computer Interfaces. PLOMS Review Journal, 1(1). 2024.

[91] J. Fitzgerald. Et. Al. Moving a missing hand: children born with below elbow deficiency can enact hand grasp patterns with their residual muscles. Journal of NeuroEngineering and Rehabilitation, 21(1), 13. 2024

[92] D. Segura. Et. L. Upper Limb Prostheses by the Level of Amputation: A Systematic Review. Prosthesis, 6(2), 277-300. 2024.

[93] Y. Yang, e.al. Muscle redistribution technique for expressing motion intention in patients with wrist-level amputation. Journal of Hand Surgery (European Volume), 49(1), 100-102. 2024

[94] P. G. Kulkarni, et. al. Overcoming challenges and innovations in orthopedic prosthesis design: an interdisciplinary perspective. Biomedical Materials & Devices, 2(1), 58-69. 2024

[95] A. Khang, Medical Robotics and AI-Assisted Diagnostics for a High-Tech Healthcare Industry. IGI Global. 2024

[96] C. Mennella, U. Maniscalco, Ethical and regulatory challenges of AI technologies in healthcare: A narrative review. Heliyon. 2024

[97] J. Park, L. Lee, Soft Sensors and Actuators for Wearable Human–Machine Interfaces. Chemical Reviews. 2024.