Application of AI-powered computer vision for improving the functionality of prosthetic devices.

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Abstract

The integration of artificial intelligence (AI) and computer vision in prosthetic devices has revolutionized assistive technologies, enhancing mobility, adaptability, and user experience. AI-powered prosthetics rely on real-time sensor fusion, advanced machine learning algorithms, and edge computing to enable dynamic adaptation to user movements and environmental changes. Real-time processing, power efficiency, and computational optimization remain critical challenges in ensuring seamless prosthetic functionality. This chapter explores cutting-edge advancements in AI-driven computer vision techniques for prosthetic control, emphasizing real-time data processing, energy-efficient AI hardware, and sustainable power solutions. The role of edge AI in on-device processing is examined, enabling prosthetic systems to function independently with reduced latency and enhanced privacy. Sustainable power management strategies, including energy harvesting and wireless power transfer, are discussed to improve the longevity and usability of intelligent prosthetics. The chapter also highlights challenges in sensor data integration, computational resource constraints, and adaptive AI modeling, proposing innovative solutions to address these limitations. By leveraging AI-powered computer vision, real-time decision-making, and energy-efficient design, next-generation prosthetic devices can offer superior functionality, increased autonomy, and improved quality of life for users.

Keywords: AI-powered prosthetics, computer vision, real-time processing, edge computing, energy-efficient AI, sustainable power solutions

Introduction

The integration of artificial intelligence (AI) and computer vision in prosthetic devices has transformed the field of assistive technology, offering unprecedented levels of functionality and adaptability [1]. Traditional prosthetic limbs, which relied on mechanical controls and limited sensory feedback, often failed to provide natural and intuitive movement [2]. AI-powered prosthetics, on the other hand, leverage advanced computational models and multimodal sensor fusion to enhance precision and responsiveness [3]. By incorporating real-time data processing

from electromyography (EMG) sensors, inertial measurement units (IMUs), and high-resolution cameras, these intelligent systems can interpret user intent and execute movements with remarkable accuracy [4]. Achieving seamless real-time adaptation in AI-driven prosthetics remains a complex challenge due to computational constraints, latency issues, and the need for energy-efficient processing [5].

Real-time processing is a fundamental requirement for AI-powered prosthetics to ensure natural movement and user comfort [6]. Prosthetic devices must process vast amounts of sensory data in milliseconds to generate appropriate motor responses [7]. Delays in computation can lead to unnatural or sluggish movements, reducing the effectiveness of the prosthetic system [8]. To address this, edge AI implementations have gained prominence, enabling on-device processing with reduced latency and minimal reliance on cloud-based computations [9]. By deploying optimized deep learning models and neural network architectures such as long short-term memory (LSTM) networks and convolutional neural networks (CNNs), prosthetic devices can predict user intent and adjust movements instantaneously [10]. Despite these advancements, achieving a balance between computational speed and power consumption remains a key challenge in real-time AI processing [11].

Sensor fusion plays a crucial role in improving the accuracy and adaptability of intelligent prosthetic systems [17]. By integrating multiple sensory inputs, including muscle activity from EMG sensors, motion data from IMUs, and environmental feedback from computer vision systems, prosthetic devices can make more informed decisions [18]. This multimodal approach enables seamless adaptation to various terrains, obstacle detection, and predictive movement generation [19]. Challenges such as data synchronization, signal noise reduction, and real-time computational overhead must be addressed to enhance the reliability of sensor fusion in prosthetic systems [20]. Advanced filtering techniques, including Kalman filters and hidden Markov models, have been employed to refine sensor data and improve decision-making accuracy [21]. The implementation of AI-driven predictive analytics further strengthens the capability of prosthetic systems to anticipate user actions and optimize motor responses [22].