Humanizing Humanoids: An Extensive Review on the Potential of Prosthetic Robotic Arm with Integrated Monitoring System for Disabled People

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Abstract This review offers an in-depth review of current developments in patient monitoring technologies and prosthetic robotic arms, with a focus on their application for children with disabilities. These prosthetic arms' design, development, and testing—which aspire to imitate the functions of human arms—are thoroughly explored. The paper also examines the application of virtual reality in user training and the significance of performance assessment in enhancing the functioning and design of the prosthetic. Additionally, numerous case studies are used to illustrate the various ways that robotic arms are used in industrial and rehabilitation contexts. It is emphasized as a potential way to raise the standard of care for kids with disabilities: the integration of patient monitoring systems and prosthetic robotic arms. The review attempts to highlight topics that need further research and lay a platform for future studies in this field.

Keywords Prosthetic robotic arms · Patient monitoring systems · Rehabilitation · Virtual reality training · Assistive technologies

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1 Introduction to Prosthetic Robotic Arms and Patient Monitoring Systems

Technology's advent has significantly improved medical and healthcare, with the emphasis on wearable and assistive technologies [1–5]. These devices are created to simulate the operation of a human arm in the field of prosthetics, particularly in the creation of robotic arms, giving people who have lost their limbs, including children, the capacity to do daily tasks independently. It is impossible to overestimate the significance of these prosthetic robotic arms, particularly in consideration of their influence on the lives of impaired children [6–14]. Children with disabilities, in particular, encounter special difficulties on a daily basis. Their capacity to connect with their environment, carry out simple chores, and engage in social activities can all be greatly impacted by the loss of an arm. By giving these children a functioning alternative that can carry out activities ranging from basic grasping to complicated movements, prosthetic robotic arms can help mitigate these difficulties [6–8]. Patient monitoring systems have advanced significantly, as well, in addition to prosthetic arms. As they offer real-time information regarding a patient's health, these systems are essential in healthcare settings. These monitoring systems can track the use and effectiveness of prosthetic arms for impaired children, providing useful information that can be used to make the necessary corrections or enhancements [9–11, 15–20].

As demonstrated in Fig. 1 [6], the field of prosthetic robotic arms and patient monitoring systems is quickly developing, with new research and technological improvements appearing often. However, a thorough analysis that synthesizes these advancements is required, especially those that concern children with disabilities. The goal of this analysis is to give a thorough overview of recent advancements in patient monitoring systems and prosthetic robotic arms. This includes a look at how these technologies were created and put into use, as well as the problems and constraints that still exist today. This review attempts to do three things: highlight the status of the subject, point out areas that require more research, and lay the groundwork for future investigations [6–15, 21–30]. The integration of these two technologies—specifically, how patient monitoring systems and prosthetic robotic arms might be utilized together to enhance the quality of care for children with disabilities—will also be a major emphasis of this review. This review attempts to emphasize the possible advantages and difficulties of this integration, because this field of study is still relatively new [12–17].

2 Current Progress and Developments in Prosthetic Robotic Arms

Prosthetic robotic arm design and execution are complex, multiple operations that demand a thorough understanding of both human anatomy and the field of robotics. The goal is to create a technology that can as closely as possibly mimic the functions


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Fig. 1 Anthropomorphic robotic arm construction [6]

of a human arm. This requires building a machine that can perform a wide range of motions and react to user input in a way that feels natural and intuitive [6–9]. The pursuit of anthropomorphic designs is one approach to the creation of prosthetic robotic arms. To provide a more organic and intuitive user experience, these designs aim to mimic the shape and functionality of a human arm. A prosthetic limb that replicates the structure and functioning of a human arm is being developed, according to prior studies [6–9], and will give users a high level of functionality and control. These designs require a combination of mechanical engineering, electronics, and software development to be put into practice. The software that controls the arm's operation must be developed and put through rigorous testing, just as the mechanical and electronic parts of the arm must be painstakingly built and made. This is a difficult, multifaceted procedure that needs a lot of organization and experience [6–9]. Technically, a user must receive training on how to operate and interact with a prosthetic robotic arm before they may use it efficiently. This stage of the process is crucial, because it has a big impact on how well the user can use the prosthetic. The use of virtual reality (VR) in this training is a novel method [28]. Users can practice using the prosthetic in a protected and safe environment, thanks to virtual reality (Fig. 2). An accurate simulation of an anthropomorphic prosthetic hand is used in a VR training platform, according to prior research, allowing users to practice using the prosthetic in a range of settings [28–31]. The user's comfort and confidence with the prosthetic could be improved using VR in training. VR can help users become more familiar with the prosthetic and more at ease using it in their daily life by offering a realistic and immersive training environment [28–31]. This might result in a more seamless transition to and greater adaptability to using the prosthetic arm, thus enhancing the user's quality of life.

The performance of a prosthetic robotic arm must be assessed once it has been carefully developed, put into use, and the user has received the necessary training. This entails a thorough evaluation of the prosthetic's performance in a range of scenarios and tasks as well as how well it meets the unique demands of the user. A wide range of techniques can be used for performance assessment, including user feedback, objective performance indicators, and the use of specialist testing rigs [32–37]. The value of user feedback cannot be overstated, because it offers firsthand perceptions into the user's experience, identifying areas of success and areas that

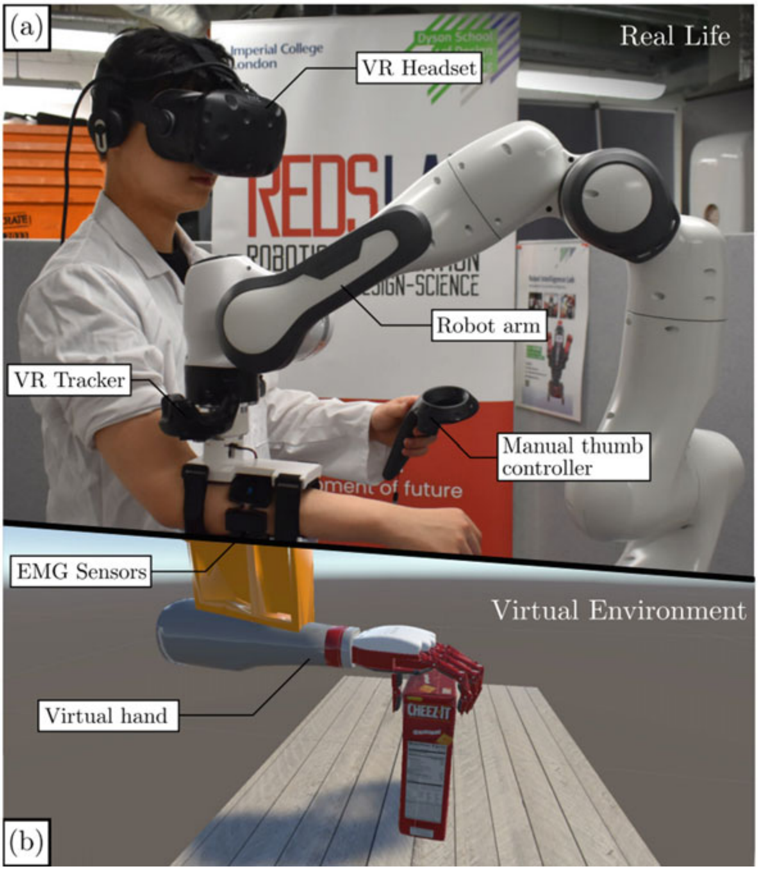

Fig. 2 The virtual hand is attached below the user's forearm on the suggested robot-enhanced virtual reality training platform, which may be used both in real life (**a**) and in virtual reality (**b**) [28]

could use improvement. On the other hand, objective performance metrics provide quantifiable information about the prosthetic's performance, such as its efficiency, precision, and dependability in carrying out tasks. In addition to this, testing rigs can be used to replicate actual environmental factors. A rig that can deliver dynamic loading to the prosthesis is described in earlier research, imitating the stresses and motions the prosthetic would experience in real-world operation [32–37]. Since it simulates the conditions the prosthetic would encounter in the user's normal life, this enables a more accurate evaluation of its functionality. Performance evaluation is a crucial stage in the development process, since it offers priceless feedback that can be used to improve the prosthetic's design and functionality. The iterative design and development process relies on this feedback loop of evaluation and improvement. It makes sure that the prosthetic device is not only useful but also easy to use and adapted to the individual requirements of the user. It is possible to develop a prosthetic that better satisfies the user's needs and improves their quality of life by regularly assessing and improving the prosthetic's performance [32–37]. The final product will be a tool that can genuinely integrate into the user's life, giving them more independence and enhancing their general well-being, thanks to the iterative process of review and development [32–37].

3 Diverse Applications and Case Studies of Robotic Arms in Rehabilitation and Industry

Robotic arms offer a lot of potential for use in the field of rehabilitation, especially in helping stroke patients recover. Rehabilitation is essential for helping patients restore their independence and quality of life after a stroke, because these functions are frequently lost [18–20]. Previous studies give an illustration of how robotic arms can be used in this situation. The researchers describe a computer program called "OnTrack" that makes use of a robotic arm to help patients with arm and hand workouts. Based on the patient's progress, the system provides real-time feedback and modifies the exercises' degree of difficulty [18–20]. There are various benefits of using robotic arms in rehabilitation. They can provide dependable and targeted help, enabling more efficient and focused activities. They can also give patients immediate feedback, which helps them grasp their progress and stay motivated. Additionally, they can be utilized in a home environment, providing a more practical and open method of therapy [18–20]. Beyond healthcare, a wide range of uses for robotic arms have been developed, with aquatic product sorting being one such example.

Robotic arm integration in this industry can greatly increase sorting process accuracy and efficiency, resulting in better product quality and reduced waste [38–50]. An example of a system that uses a robotic arm with intelligent vision to classify aquatic products comes from a case study from earlier research. The products are photographed using a camera in this system, and the photos are then processed with advanced image analysis software to determine their attributes. The robotic arm may then systematically sort the items based on these traits [38–50]. The potential of robotic arms in industrial applications is highlighted by this case study. The system can increase efficiency, reduce the possibility of human error, and ensure a constant level of product quality by automating the sorting process. Additionally, the system can adapt to a wide range of items and sorting criteria, thanks to the use of intelligent vision, making it a flexible and adaptable solution [38–53]. Table 1 describes various case studies that might be related to the development and the application of prosthetic robotic arms.

Table 1 Various research works related to the development and the application of prosthetic robotic arms

Studies	Classification	Description
[1, 4, 14, 20, 23, 24, 42, 47, 49]	Healthcare and rehabilitation applications	Focus on robotic arms and IoT in healthcare. Include patient monitoring, assisting the disabled, and rehab exercises. Related to prosthetic arm development for limb loss
[2, 3, 5, 12, 18, 50]	Assistive devices and rehabilitation	Discusses assistive devices like wheelchairs and robotic arms for rehab and quality of life improvement. Aims to restore or enhance mobility
[6, 28, 32, 36, 44]	Prosthetic arm design and testing	Covers design, testing, anthropomorphic designs, VR training, performance assessment, and neural control of prosthetic arms
[7, 8, 10, 11, 16, 17, 25, 26, 33, 34, 37, 39, 40, 43, 45, 48]	Manufacturing and material processing	These studies discuss various aspects of manufacturing and material processing, including machining, finite element method, and material properties. While not directly related to prosthetic arm development, the techniques and methods discussed could potentially be applied in the manufacturing process of prosthetic arms

(continued)

Table 1 (continued)

Studies	Classification	Description
[9, 38, 41]	Industrial applications	These studies discuss the use of robotic arms in industrial applications, specifically in aquatic product sorting. While not directly related to prosthetic arm development, they demonstrate the versatility of robotic arms and the potential for cross-application of technologies

4 Summary

Prosthetic robotic arms and patient monitoring devices are evolving swiftly. This field has promising research and development opportunities. IoT is being used in patient monitoring. Studies suggest that IoT technology can monitor patients in real time, improving care. Future IoT research could use machine learning to predict health consequences from patient data. Prosthetic robotic arm advanced VR training is another intriguing idea. Current platforms are safe and controlled, but they could be more realistic and accurate. Future VR research could improve training using haptic feedback. Research gaps remain despite considerable advances. Research is needed for impaired children's prosthetic robotic arms and patient monitoring systems. Prosthetic robotic arms and patient monitoring systems for children must consider their needs and abilities.

Prosthetic robotic arms and patient monitoring devices are hard to make. These complex systems demand technical expertise to build and implement. Precision control is essential for prosthetic robotic arm development. These devices must accurately mimic human-arm movements. Human-arm anthropomorphic designs are tough [6]. Patient monitoring systems struggle with data. These technologies generate large amounts of data that must be collected, delivered, and processed rapidly. This needs complex data management systems and raises security and privacy concerns [9, 24, 35]. Current systems have technological challenges and constraints. The VR training systems are unrealistic. VR lets people practice using prosthetic robotic arms in a controlled setting, although platforms may not replicate the experience. This may impair training efficacy and fail to prepare users for prosthetic use [28–31]. Personalized patient monitoring is another concern. Current health data systems may not be individualized. This may lower efficacy and patient care [10, 24, 35]. Prosthetic robotic arms and patient monitoring systems must overcome these challenges to advance. Research, innovation, and cross-disciplinary collaboration are needed.

Acknowledgements The author wishes to express profound gratitude to the Ministry of Higher Education for their generous support of this study through the Fundamental Research Grant Scheme (FRGS), under the grant number FRGS/1/2019/TK04/UMP/02/15 (University Reference: RDU1901199). This research would not have been possible without their commitment to fostering academic exploration and innovation. Additionally, heartfelt thanks are extended to the Universiti Malaysia Pahang Al-Sultan Abdullah for their invaluable support and financial assistance under the grant RDU Number RDU230328.

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