Augmented Recovery

Transforming Post-Surgery Rehabilitation

Through Interactive Technologies

Pushkar V   
*Computer Science and Engineering*  
*Vidyavardhaka College of Engineering* Mysuru, India  
pushkarv0403@gmail.com

Ujwal R   
*Computer Science and Engineering*  
*Vidyavardhaka College of Engineering*Mysuru, India  
ujwal.r778@gmail.com

Saanvi Ravi  
*Computer Science and Engineering*  
*Vidyavardhaka College of Engineering*Mysuru, India  
saanviravee@gmail.com

Suparna D S  
*Computer Science and Engineering*  
*Vidyavardhaka College of Engineering*Mysuru, India  
suparnasharath7@gmail.com

Madhusudhan HS  
*Computer Science and Engineering*  
*Vidyavardhaka College of Engineering*Mysuru, India  
mady187@gmail.com

*Abstract*—Virtual reality (VR) and augmented reality (AR) technologies are being investigated for rehabilitation, particularly for individuals recuperating from shoulder operations. By producing captivating and engaging settings, these technologies improve on conventional rehabilitation techniques. through improved motivation, patient involvement, and real-time feedback. AR wearable applications such as Microsoft HoloLens and motion-tracking VR systems Capabilities facilitate efficient rehabilitation workouts. Research indicates that VR-based initiatives can enhance motor function, pain relief, and shoulder joint range of motion. Nonetheless, issues including cost, safety concerns, and the requirement for clinical validation continue to exist.

Keywords—Augmented Reality, Virtual Reality, Shoulder Rehabilitation, Post-Surgery Recovery, Real-Time Feedback, Patient Engagement, Pain Management, Motion Tracking, Clinical Validation, Telehealth

1. Introduction

There are now more opportunities to improve patient recovery thanks to the use of Augmented Reality (AR) and Virtual Reality (VR) technologies into medical rehabilitation programs, especially for patients recuperating from shoulder surgery. In recent years, AR and VR have been increasingly recognized as effective tools in medical treatment, thanks to their ability to create immersive and interactive environments that help patients adhere to rehabilitation exercises. There are now more opportunities to improve patient recovery through the use of Augmented Reality (AR) and Virtual Reality (VR) technologies into medical rehabilitation programs, especially for patients recuperating from shoulder surgery.

Shoulder rehabilitation after surgery is crucial in regaining functionality and reducing pain. Standard rehabilitation methods typically involve repeated, specific physical exercises guided by a therapist. However, traditional rehabilitation can sometimes be limited by patient compliance and motivation issues. AR and VR technologies offer a solution to these challenges by providing patients with real-time feedback and interactive guidance, thus enhancing engagement and adherence. Unlike conventional therapy, these technologies allow patients to perform exercises in a simulated environment, enabling immersive experiences that help maintain motivation over extended periods. The significance of AR and VR lies not only in providing a platform for exercising but also in fostering an enjoyable and effective recovery process.

AR and VR applications designed for shoulder rehabilitation include specialized wearable devices and software interfaces that track patient movement, monitor progress, and provide visual cues for correct posture and movement. For instance, wearable AR devices like the Microsoft HoloLens provide real-time marker less tracking of hand and shoulder movements, which can help patients perform exercises more accurately. This characteristic is especially beneficial for patients going through shoulder rehabilitation , as it enables them to receive instant feedback and corrections while performing exercises. Similarly, VR systems such as Oculus Quest and Kinect capture motion information and match it against standard movement patterns. This capability allows patients to visualize their movements within a virtual space, creating a supportive framework for recovering shoulder function and range of motion.

In addition to the enhanced feedback and immersive experience, AR and VR-based rehabilitation systems also provide significant flexibility in terms of location. Considering these technologies are home-useable, they provide a capable choice for patient who is unable to see a therapist on a regular basis. Remote rehabilitation has proven especially valuable in the wake of global events like the COVID-19 pandemic, which has restricted patients’ access to in-person care. With the option to perform exercises remotely, patients can adhere to rehabilitation programs from the safety and convenience of their homes, maintaining consistent progress without frequent in-person visits. Additionally, remote therapy options help reduce the financial burden on patients by eliminating transportation costs and minimizing the frequency of hospital visits.

Despite these promising applications, AR and VR-based rehabilitation are not without challenges. Safety is a primary concern, as improper use of these technologies could lead to further injury. Ensuring that patients perform movements correctly in a virtual environment is critical, and the need for supervision and guidance remains even when technology is used. Additionally, physiotherapists and clinicians point to the ergonomic limitations of current VR and AR devices, which may be uncomfortable for long-term use or have visual restrictions that might obstruct a patient's experience. In order to overcome these obstacles, further research and refinement in both hardware and software aspects of AR and VR systems, making these technologies more user-friendly and accessible for all patients.

For AR and VR technologies to achieve broader acceptance in shoulder rehabilitation, clinical validation is essential. Research studies are needed to establish standardized protocols and evaluate the clinical efficiency of these technologies compared to traditional methods. Initial encouraging results from randomized controlled trials have demonstrated that patients utilizing VR and AR-based rehabilitation had improved shoulder range of motion and motor function. However, larger-scale trials involving more diverse patient populations will be necessary to confirm these findings and ensure the applicability of these technologies in real-world clinical settings. Additionally, integration with telehealth platforms could expand the reach of AR and VR rehabilitation, allowing patients in remote areas to access high-quality care and follow-up support from their healthcare providers.

In light of these challenges and the potential benefits, this project proposes a Mixed Reality (MR) rehabilitation system that combines AR and VR elements to support shoulder rehabilitation. The proposed MR system leverages the immersive capabilities of VR with the real-time tracking features of AR, creating an interactive environment tailored to shoulder recovery. The system is designed to guide patients through exercises using a VR headset equipped with in-built sensors for precise motion tracking. A user-friendly interface presents on-screen instructions for each exercise, while audio-visual feedback provides corrections to ensure proper form. Additionally, the MR system incorporates remote monitoring, allowing therapists to review patient progress and adjust the rehabilitation program as necessary, without requiring in-person visits. Data from each session is stored in the cloud, allowing the patient and therapist to communicate easily.

In summary, AR and VR technologies hold significant promise in improving the outcomes of shoulder rehabilitation programs by offering an engaging, interactive, and accessible approach to post-surgery recovery. These systems are designed to enhance patient motivation and compliance, address existing barriers, and potentially reduce recovery times through real-time feedback and immersive experiences. However, continued advancements in clinical research, safety protocols, and user-centred design will be essential to overcoming current limitations and utilizing AR and VR to their fullest potential in medical rehabilitation The healthcare sector can give patients useful tools to restore function and enhance quality of life after shoulder surgery by integrating these technologies into routine rehabilitation procedures.

1. RELATED WORK

The application of AR and VR technology in shoulder rehabilitation has been explored in various studies, demonstrating the potential benefits of these systems in improving patient engagement and rehabilitation outcomes. Condino et al. [1] developed an AR-based shoulder rehabilitation tool using the Microsoft HoloLens. This system enables real-time marker less tracking of shoulder movement, providing an immersive and interactive experience for patients. Even so, drawbacks such a limited field of vision and the possibility of visual fatigue were noted, emphasizing areas where additional advancement could improve user efficiency and comfort.

Brady et al. [2] conducted a study examining physiotherapists' beliefs and perspectives on using VR for managing musculoskeletal shoulder pain. The findings suggested that VR could significantly improve patient compliance and engagement by reducing movement-related fear and enhancing motivation. Despite these benefits, therapists expressed concerns about the safety and practicality of VR in rehabilitation, indicating that further research is required to overcome these problems before they can be widely implemented.

Berton et al. [3] investigated the psychological impact of VR, AR, and gamification in orthopedic rehabilitation. Their results demonstrated that these technologies, when combined with telerehabilitation, could provide effective remote care options, which are especially advantageous for patients with restricted access to in-person care. However, they noted that the current effectiveness of these systems remains mixed, emphasizing the need for clinical validation to ensure consistent outcomes across diverse patient populations.

Kun et al. [4] proposed a VR-based shoulder joint rehabilitation training system that focuses on improving shoulder range of motion and motor function. Their system demonstrated effectiveness in controlled environments, showing significant improvements in shoulder function among users. Despite these promising results, the study highlighted limitations in applying this technology to real-world settings, suggesting that further adaptations are necessary to make VR-based rehabilitation accessible and practical for home use.

Sveistrup et al. [5] compared VR-delivered rehabilitation programs with conventional exercise programs for motor recovery. Their study found that VR-based programs could be as effective as traditional methods, offering potential advantages for patients undergoing home-based rehabilitation. However, the effectiveness of VR varied among users, suggesting a need for further research to tailor VR rehabilitation to individual patient needs.

Gumaa et al. [6] conducted a meta-analysis on the effectiveness of VR in orthopaedic rehabilitation. The review highlighted VR's potential in improving range of motion and patient motivation, particularly in post-surgery recovery. However, The authors also out that further thorough research are required to confirm these findings, as well as to standardize VR interventions for shoulder rehabilitation. The study emphasized the need for larger trials to evaluate long-term outcomes and establish evidence-based guidelines for incorporating virtual reality into routine rehabilitation procedures.

Chen et al. [7] explored the use of an immersive VR-based exercise system in post-stroke upper limb motor rehabilitation. Their proof-of-concept trial demonstrated that VR could significantly improve shoulder flexion and abduction, in addition to perceived motor function. Patients reported positive experiences, supporting the application of VR for post-surgery rehabilitation. However, the study also acknowledged the necessity for additional research to validate these results across a broader demographic.

Mishra et al. [8] discussed the applications of VR in neurosurgery, emphasizing the benefits of VR for preoperative planning and simulation. Since their attention was not solely on shoulder rehabilitation, their findings contribute to the broader context of VR applications in medical recovery, highlighting VR's role in improving surgical outcomes and enhancing patient safety. These insights underscore the potential of VR as a complementary tool in rehabilitation settings, particularly in planning and customizing patient care.

Negrillo-Cárdenas et al. [9] reviewed the role of VR and AR in orthopaedic trauma surgery, from diagnosis to rehabilitation. They highlighted the value of these technologies in postoperative recovery, especially in enhancing patient engagement and reducing recovery time. The review concluded that while VR and AR show promise, more thorough research is required to address limitations such as cost and technological barriers to enable widespread clinical adoption.

Sadeghi et al. [10] explored current and future applications of AR, VR, and MR in cardiothoracic surgery, identifying key benefits in rehabilitation and remote monitoring. Though focused on cardiothoracic applications, their findings align with the potential benefits of these technologies in shoulder rehabilitation, particularly in terms of accessibility and patient monitoring in remote settings. The study suggests that AR and VR might be crucial to in providing personalized, remote rehabilitation programs, which could be extended to shoulder rehabilitation.

1. PROPOSED SYSTEM

Our proposed Mixed Reality Rehabilitation System, combines both Augmented Reality (AR) and Virtual Reality (VR) to support post-shoulder surgery recovery, offering patients an engaging and accessible approach to rehabilitation. It is designed to address the challenges observed in traditional rehabilitation, such as low patient motivation and compliance, as well as the need for consistent supervision. By integrating AR and VR elements, our system provides an immersive environment that encourages adherence to prescribed exercises through real-time feedback and interactive experiences.

The system comprises several modules that facilitate comprehensive patient support and enable therapist monitoring. Key components include:

## User Interface (UI):

The system uses a VR headset (e.g., Oculus Quest 2) equipped with built-in sensors to guide the user through exercises. Clear, on-screen instructions are given to patients, enabling them to perform shoulder rehabilitation activities safely and intuitively. The UI presents a seamless experience for users, promoting comfort and minimizing distractions that could hinder rehabilitation progress.

## Real-Time Feedback:

Inspired by studies like Condino et al. [1] and Kun et al. [4], our system features motion tracking and marker less hand tracking, similar to the Microsoft HoloLens technology, to ensure precise monitoring of patient movements. This feedback loop corrects patient form, preventing improper motions that could be uncomfortable or injury. Patients receive audio-visual cues for guidance, making it easier to perform exercises accurately.

## Remote Monitoring and Data Storage:

Patient performance data is automatically recorded and uploaded to a cloud-based storage system, allowing therapists to review the data remotely. As suggested by Brady et al. [2] and Berton et al. [3], this method improves accessibility, particularly for patients who might find it difficult to routinely attend in-person sessions. Therapists can monitor progress, adjust exercise regimens, and provide feedback without requiring the patient to visit the clinic, thus supporting continuous rehabilitation.

## Adaptable Exercise Modules:

The system includes adaptive exercises tailored to individual patient needs, inspired by Kun et al. [4] and Sveistrup et al. [5], who highlight the importance of exercises that align with a patient's recovery stage. The system’s flexibility ensures that patients receive appropriate challenges, fostering steady progress and reducing recovery time.

By leveraging AR and VR, it is positioned as an accessible, immersive rehabilitation solution that offers patients effective post-surgery support. The system is intended not only to improve rehabilitation outcomes but also to address common barriers like safety concerns, remote access, and patient motivation. With its comprehensive and adaptable structure, it has the potential to transform post-surgical shoulder recovery, providing both patients and therapists with a powerful tool for improved rehabilitation outcomes.

1. SYSYTEM ARCHITECTURE

## User Interaction Module:

The User Interaction Module serves as the primary interface for patients engaging with the rehabilitation system. Upon launching the application, users are guided through a setup process that calibrates the AR/VR environment to their specific rehabilitation needs. This module allows patients to select their rehabilitation program based on their surgery type and personal preferences. The interface is designed to be intuitive and user-friendly, incorporating visual aids and audio prompts to facilitate easy navigation. Patients can also create objectives and monitor their progress, and receive reminders for their rehabilitation sessions, enhancing motivation and adherence to the therapy.

## Immersive Rehabilitation Environment:

This module leverages AR and VR technologies to create an immersive rehabilitation environment tailored for post-shoulder surgery patients. Utilizing devices such as the Oculus Quest for VR and Microsoft HoloLens for AR, patients can engage in realistic simulations that replicate physical exercises. The system tracks the user’s movements in real-time, providing immediate feedback on performance. This immersive setup not only helps in pain management but also promotes engagement by transforming tedious rehabilitation exercises into interactive and enjoyable activities, significantly improving patient compliance.

## Motion Tracking and Feedback System:

The Motion Tracking and Feedback System is integral to the rehabilitation process, utilizing advanced motion capture technology to monitor patients' movements during exercises. Using sensors and cameras, the system analyzes the user's range of motion and provides real-time feedback. For instance, if a patient performs an exercise incorrectly, the system will issue corrective prompts to ensure proper technique. This feature enhances motor learning and recovery, allowing for personalized adjustments to the rehabilitation program based on the patient's specific progress and needs.

## Gamification and Motivation Engine:

To enhance patient motivation, the Gamification and Motivation Engine incorporates game-like elements into the rehabilitation process. This module rewards patients for completing exercises, achieving milestones, or improving their performance. By integrating points, levels, and achievement badges, the system transforms the rehabilitation experience into an engaging game. Studies indicate that this gamification approach significantly boosts patient motivation and adherence, making rehabilitation less daunting and more enjoyable.

## Remote Monitoring and Telehealth Integration:

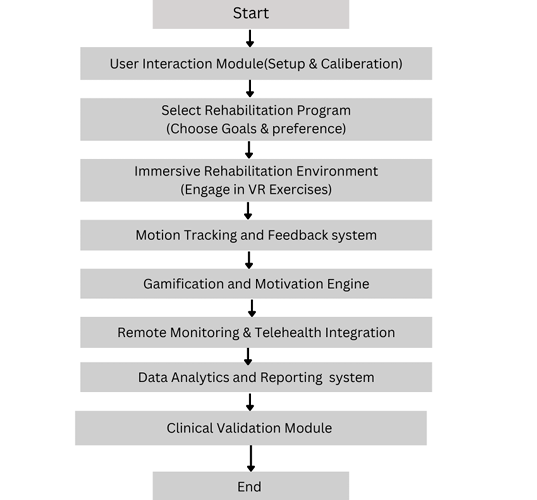
The Remote Monitoring and Telehealth Integration module facilitates continuous patient monitoring and enables healthcare providers to maintain regular contact with patients. Through this feature, therapists can track patients' progress remotely and make necessary adjustments to their rehabilitation programs. The system can also send alerts to therapists if it detects any issues, such as insufficient movement or deviations from prescribed exercises. This capability ensures that patients receive high-quality care, even from a distance, while also reducing transportation costs and hospital visits.

## Analytics of Data and Reporting System:

The Analytics of Data and Reporting System compiles and analyse data from patient interactions and progress throughout their rehabilitation journey. This module generates reports that outline improvements in mobility, strength, and overall function. Medical professionals can access these analytics to make well-informed choices regarding treatment plans. Additionally, the system can identify trends and outcomes across patient populations, offering insightful information about the efficacy of AR/VR rehabilitation approaches.

## Clinical Validation Module:

As AR and VR technologies continue to evolve, the Clinical Validation Module plays a vital part in ensuring that the implemented systems are effective and safe for patients. This module focuses on conducting clinical trials and gathering proof of the efficacy of AR and VR interventions in rehabilitation. It works closely with research institutions to validate findings and improve the technologies based on patient feedback and clinical outcomes. By prioritizing clinical validation, this module aims to build trust and acceptance of AR/VR rehabilitation methods within the medical community.



1. VR-Based Rehabilitation System Workflow for Post-Surgical Recovery.
2. COMPARATIVE ANALYSIS

The Explorative Matrix of AR/VR Innovations in Rehabilitation and Orthopaedic Care table illustrates a comparison of various papers, highlighting their features, advantages and disadvantages.

1. Explorative Matrix of AR/VR Innovations in Rehabilitation and Orthopaedic Care

| Title | ***Authors*** | ***Features*** | ***Advantages*** | ***Disadvantages*** |
| --- | --- | --- | --- | --- |
| Effectiveness, safety and patients’ perceptions of an immersive system for virtual reality | Chen et al. (2023) | Immersive VR exercise system focused on post-stroke upper limb motor rehabilitation. | Positive patient perceptions and improved outcomes mentioned in the study. | Limited generalizability to different kinds of rehabilitation beyond upper limb post-stroke recovery. |
| The role of augmented virtual and reality in orthopedic trauma surgery | Negrillo-Cárdenas et al. (2020) | Discusses AR and VR applications from diagnosis to rehabilitation. | Enhances surgical education and training, leading to better-informed rehabilitation protocols. | Needs further clinical validation and large-scale studies to support its routine use in clinical practice. |
| Current and Future Applications of Virtual, Augmented, and Mixed Reality | Sadeghi et al. (2020) | Examines applications of AR/VR in various surgical fields, including rehabilitation. | Potential for improved patient engagement and tailored rehabilitation experiences through technology. | Challenges related to high costs and accessibility may hinder widespread adoption in rehabilitation settings. |
| Shoulder Joint Rehabilitation Training System Based on Virtual Reality | Kun et al. (2021) | Provides a structured VR training program specifically for shoulder rehabilitation. | Demonstrates improved functional outcomes and pain management capabilities. | Technical expertise needed for system setup may limit implementation in some clinical settings. |
| Experimental Studies of Virtual Reality-Delivered Compared to Conventional Exercise Programs | Sveistrup et al. (2003) | Compares VR-based exercises with traditional rehabilitation methods. | Shows significant improvement in patient engagement and compliance during rehabilitation exercises. | Lack of long-term follow-up data in studies to validate ongoing effectiveness. |
| Is Virtual Reality Effective in Orthopedic Rehabilitation? | Gumaa & Youssef (2019) | Systematic review assessing the effectiveness of VR in orthopedic rehabilitation. | Strong evidence supporting improved patient outcomes and engagement in rehabilitation processes. | Mixed results on clinical effectiveness compared to traditional methods, indicating a need for more comparative studies. |
| Wearable Augmented Reality Application for Shoulder Rehabilitation | Condino et al. (2019) | Uses Microsoft HoloLens for real-time marker less tracking and user-specific stimuli. | Increases patient comfort and engagement during rehabilitation. | Limited accessibility and potential technology-related barriers for some patients. |
| Physiotherapist beliefs and perspectives on virtual reality | Brady et al. (2023) | Integrates VR into rehabilitation practices for musculoskeletal shoulder pain management. | Enhances patient motivation and compliance through engaging exercises. | Requires further clinical validation to ensure effectiveness across diverse patient populations. |
| Virtual Reality, Augmented Reality, Gamification, and Telerehabilitation | Berton et al. (2020) | Combines various technologies for a holistic rehabilitation approach. | Offers remote care delivery, reducing transportation costs while maintaining clinical interactions. | High costs associated with technology implementation and potential drop-out rates due to unfamiliarity. |

1. RESULT

The integration of Augmented Reality (AR) in rehabilitation programs for post-shoulder surgery patients shows significant potential to enhance outcomes and engagement. Utilizing devices like Microsoft HoloLens, AR provides real-time feedback and guidance during rehabilitation exercises, allowing patients to visualize movements and receive immediate corrections. This instant feedback is crucial for effective motor learning, fostering confidence as patients engage with their exercises.

Research highlights that AR significantly improves shoulder function post-surgery. For instance, patients using AR tools demonstrated greater improvements in their performance compared to those undergoing traditional rehabilitation. The Disability of the Arm, Shoulder, and Hand (DASH) scores showed an average reduction of 47-64% following AR interventions, indicating effectiveness in pain reduction and increased range of motion.

AR also positively impacts the psychological aspects of rehabilitation. By incorporating gamification and interactive elements, AR enhances engagement and enjoyment, crucial for maintaining long-term motivation. Higher levels of motivation and compliance were noted by AR users, which is crucial for effective recovery. The immersive nature of AR can distract from pain, allowing patients to focus better on therapeutic tasks.

However, challenges exist in implementing AR in rehabilitation, such as high costs, the requirement for specific technical knowledge, and potential accessibility issues. While initial studies yield positive results, More thorough clinical research is required to validate the long-term effectiveness and safety of AR technologies across diverse patient populations.

Future studies ought to look into these challenges by developing cost-effective solutions and strategies to increase patient familiarity with AR. Longitudinal studies are essential to assess the sustainability of observed improvements and refine these technologies for broader application.

In summary, AR integration in post-surgical shoulder rehabilitation represents a transformative approach that enhances patient engagement, motivation, and functional recovery. Tailored, interactive experiences can redefine traditional rehabilitation practices, but continued research and clinical validation are essential to a successful integration into routine clinical care, ultimately improving the standard of care for post-shoulder surgery patients.

1. CONCLUSION

The incorporation of Augmented Reality (AR) and Virtual Reality (VR) technologies in rehabilitation for post-shoulder surgery patients has shown remarkable potential to transform traditional rehabilitation practices. These technologies create immersive and interactive environments that enhance patient engagement, motivation, and adherence to therapy, leading to improved functional outcomes and reduced pain. Studies have indicated significant benefits, including enhanced shoulder function, decreased DASH scores, and improved patient satisfaction through gamified and tailored rehabilitation experiences.

Despite the positive outcomes associated with AR and VR, challenges remain, including the requirement for comprehensive clinical validation and research into the long-term effectiveness of these technologies. Addressing issues related to costs, accessibility, and patient familiarity with AR/VR systems is necessary for widespread adoption in clinical settings.

1. FUTURE SCOPE

Future studies ought to focus on several key areas to maximize the potential of AR and VR in rehabilitation. Firstly, there is a demand for larger clinical trials to validate the effectiveness of these technologies across diverse patient populations, ensuring comprehensive understanding and applicability in real-world settings. Secondly, integrating AR and VR with other technological advancements, such as artificial intelligence and robotics, could further personalize rehabilitation programs, tailoring them to meet the needs of each patient for improved results.

Additionally, exploring innovative solutions to mitigate cost barriers and improve accessibility will be critical. Developing user-friendly interfaces and training programs can help familiarize patients and clinicians with AR/VR technologies, promoting their acceptance and incorporation into standard rehabilitation protocols.

Furthermore, establishing safety guidelines for AR and VR usage in rehabilitation will ensure patient safety during immersive exercises, minimizing the risk of injuries. Longitudinal studies should assess the sustainability of improvements gained through AR/VR rehabilitation, providing a clearer picture of their long-term benefits and informing best practices.

In conclusion, the future of rehabilitation for post-shoulder surgery patients is promising with AR and VR technologies. Continued research and innovation will enhance their effectiveness, paving the way for broader clinical application and eventually enhancing recovery results and patient care.

##### REFERENCES

[1] Condino, S., Turini, G., Viglialoro, R., Gesi, M., & Ferrari, V. (2019). Wearable Augmented Reality Application for Shoulder Rehabilitation. Electronics, 8(10), 1178. https://doi.org/10.3390/electronics8101178

[2] Brady, N., Dejaco, B., Lewis, J., McCreesh, K., & McVeigh, J.(2023).Physiotherapist beliefs and perspectives on virtual reality supported rehabilitation for the management of musculoskeletal shoulder pain: A focus group study. PLOS ONE, 18. https://doi.org/10.1371/journal.pone.0284445

[3] Berton, A., Longo, U., Candela, V., Fioravanti, S., Giannone, L., Arcangeli, V., Alciati, V., Berton, C., Facchinetti, G., Marchetti, A., Schena, E., Marinis, M., & Denaro, V. (2020). Virtual Reality, Augmented Reality, Gamification, and Telerehabilitation: Psychological Impact on Orthopedic Patients’ Rehabilitation. Journal of Clinical Medicine, 9(8), 2567. https://doi.org/10.3390/jcm9082567

[4] Kun, R., Guimei, W., Yanjie, L., Ruoxing, X., & Hong, C. (2021). Shoulder Joint Rehabilitation Training System Based on Virtual Reality Technology. 2021 13th International Conference on Measuring Technology and Mechatronics Automation (ICMTMA), 619-623. https://doi.org/10.1109/ICMTMA52658.2021.00143

[5] Sveistrup, H., McComas, J., Thornton, M., Marshall, S., Finestone, H.,McCormick, A., Babulic, K., & Mayhew, A. (2003). Experimental Studies of Virtual Reality-Delivered Compared to Conventional Exercise Programs for Rehabilitation. Cyberpsychology & Behavior, 6(3), 245-249. https://doi.org/10.1089/109493103322011524

[6] Gumaa, M., & Youssef, A. (2019). Is Virtual Reality Effective in Orthopedic Rehabilitation? A Systematic Review and Meta-Analysis. Physical Therapy, 99(10), pzz093. https://doi.org/10.1093/ptj/pzz093

[7] Chen, J., Or, C., Li, Z., Yeung, E., Zhou, Y., & Hao, T. (2023). Effectiveness, safety and patients’ perceptions of an immersive virtual reality–based exercise system for poststroke upper limb motor rehabilitation: A proof-of-concept and feasibility randomized controlled trial. Digital Health, 9, 20552076231203599. https://doi.org/10.1177/20552076231203599

[8] Mishra, R., Narayanan, M., Umana, G., Montemurro, N., Chaurasia, B., & Deora, H. (2022). Virtual Reality in Neurosurgery: Beyond Neurosurgical Planning. International Journal of Environmental Research and Public Health, 19(3), 31719. https://doi.org/10.3390/ijerph19031719

[9] Negrillo-Cárdenas, J., Jiménez-Pérez, J., & Feito-Higueruela, F. (2020). The role of virtual and augmented reality in orthopedic trauma surgery: From diagnosis to rehabilitation. Computer Methods and Programs in Biomedicine, 191, 105407. https://doi.org/10.1016/j.cmpb.2020.105407

[10] Sadeghi, A., Mathari, S., Abjigitova, D., Maat, A., Taverne, Y., Bogers, A., & Mahtab, E. (2020). Current and Future Applications of Virtual, Augmented, and Mixed Reality in Cardiothoracic Surgery. The Annals of Thoracic Surgery, 110(6), 1753-1761. https://doi.org/10.1016/j.athoracsur.2020.11.030