Blending Realities: Accessible Mixed Reality for Tremor Rehabilitation in Parkinson's Disease

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Keywords: Augmented Reality, Mixed Reality, Hand Rehabilitation, Parkinson's Disease, Assistive Device, Haptic Feedback.

Abstract: This position paper presents a novel MR-based hand motion assistance device designed for individuals with Parkinson's disease (PD)-related tremor disorders. We argue that the integration of ergonomic hardware design with adaptive MR software can significantly enhance the efficacy of tremor rehabilitation, improve patient engagement, and lead to superior functional outcomes. Our approach combines a smartphone-based MR system with an ergonomic physical support device, leveraging advanced spatial computing, computer vision algorithms, and haptic feedback technologies. This innovative solution addresses both immediate stabilization needs and long-term motor skill improvement, potentially revolutionizing home-based rehabilitation for millions of PD patients worldwide. By seamlessly blending virtual and real-world elements, our system creates immersive, interactive, and personalized therapeutic experiences that overcome the limitations of traditional rehabilitation methods. The paper discusses the design research methodology, comparative analysis with existing approaches, and the potential impact of this technology on PD rehabilitation.

1 INTRODUCTION

Parkinson's disease (PD) is a progressive neurodegenerative disorder that affects millions worldwide, with an estimated 930,000 people living with PD in the United States alone by 2020, projected to rise to 1.2 million by 2030 (Marras et al., 2021). This alarming increase underscores the urgent need for innovative therapeutic approaches. The primary motor symptoms of PD, including tremors, rigidity, and bradykinesia, significantly impact patients' quality of life and ability to perform activities of daily living (ADLs) (Dorsey et al., 2020).

Traditional rehabilitation methods often fall short in addressing the complex needs of PD patients, particularly in maintaining long-term engagement and providing personalized care. In recent years, mixed reality (MR) technologies have emerged as a promising solution for enhancing rehabilitation outcomes in various medical fields. By seamlessly blending virtual and real-world elements through advanced spatial computing and computer vision algorithms, MR offers unique opportunities to create immersive, interactive, and adaptive therapeutic experiences (Cipresso et al., 2022). This paper presents a novel MR-based hand motion assistance device designed specifically for individuals with Parkinson's-related tremor disorders. Our approach combines ergonomic physical support with MR applications to provide a comprehensive rehabilitation solution that addresses both immediate stabilization needs and long-term motor skill improvement.

The proposed system leverages the ubiquity of smartphones and advanced haptic feedback technologies to deliver accessible and cost-effective MR therapy, potentially reaching millions of patients worldwide. By integrating cutting-edge sensor technology with intuitive user interfaces based on advanced spatial mapping and object recognition techniques, our device aims to revolutionize home-based rehabilitation for PD patients. This paper argues that the combination of ergonomic hardware design and adaptive MR software can significantly improve the efficacy of tremor rehabilitation, enhance patient engagement through gamification techniques, and ultimately lead to better functional outcomes for individuals with

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Li, X. and Lei, Z.
Blending Realities: Accessible Mixed Reality for Tremor Rehabilitation in Parkinson's Disease.
DOI: 10.5220/0013321800003912

In *Proceedings of the 20th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2025) - Volume 1: GRAPP, HUCAPP and IVAPP*, pages 371-375
ISBN: 978-989-758-728-3; ISSN: 2184-4321

Parkinson's disease.

2 COMPARATIVE ANALYSIS

The landscape of PD rehabilitation has evolved significantly in recent years, with various technologies emerging to address the limitations of traditional therapies. This section provides a comparative analysis of existing approaches and highlights the unique advantages of our proposed MR-based system.

Conventional rehabilitation methods for PD typically involve a combination of physical therapy, occupational therapy, and medication management. While these approaches have shown some efficacy, they often lack the ability to provide real-time feedback and personalized adaptation to patient needs (Bloem et al., 2021).

Recent advancements in wearable technologies have led to the development of various tremor-suppression devices. For instance, researchers have introduced a wrist-worn device that uses mechanical oscillations to counteract tremors (Pahwa et al., 2022). While such devices provide immediate tremor reduction, they do not address the underlying motor control deficits or promote long-term skill acquisition. Our system combines physical stabilization with interactive MR exercises, fostering both immediate symptom relief and sustained motor learning through neuroplasticity-inducing protocols.

Virtual reality (VR) has also been explored as a tool for PD rehabilitation. Studies have demonstrated that VR-based balance training could improve postural stability in PD patients (Wang et al., 2023). However, fully immersive VR systems often isolate users from their real environment, limiting the transfer of skills to daily activities. Our MR approach bridges this gap by overlaying virtual elements onto the real world using advanced spatial mapping and object recognition techniques, allowing patients to practice tasks in a context-relevant manner with seamless integration of digital and physical environments.

Smartphone-based applications for PD management have gained popularity due to their accessibility and ease of use. Researchers have developed a mobile app for remote monitoring of PD symptoms (Arora et al., 2021). While such apps provide valuable data collection capabilities, they typically lack the physical support component crucial for tremor management. Likewise, attempts to integrate the two may still need improvements in user interface and usability (Lei and Li, 2024). In contrast, our MR-based system offers continuous monitoring and adjustment of therapy intensity based on individual performance and progress to analyze movement patterns and optimize treatment protocols.

The unique contribution of our proposed system lies in its holistic approach to PD rehabilitation. By seamlessly integrating physical support, real-time sensing, and adaptive MR exercises, we create a comprehensive solution that addresses multiple aspects of tremor management and motor skill improvement. This multifaceted approach has the potential to yield superior outcomes compared to existing single-modality interventions, as evidenced by preliminary studies showing significant improvements in both motor function and quality of life metrics.

3 DESIGN RESEARCH METHODOLOGY

Our design research methodology follows a user-centered, iterative approach to develop an effective MR-based rehabilitation system for PD patients. The process encompasses three main phases: user needs assessment, prototype development, and iterative refinement. In the initial phase, we conducted a comprehensive literature review to identify key challenges faced by PD patients in daily activities and existing gaps in current rehabilitation approaches. This was supplemented by in-depth interviews with neurologists, occupational therapists, and PD patients to gain insights into specific user needs and preferences. The findings from this phase informed the development of our initial design requirements, emphasizing the importance of ergonomic comfort, intuitive usability, and adaptive feedback mechanisms (Espay et al., 2021).

The prototype development phase involved the creation of both hardware and software components. The physical device was designed using advanced 3D modeling software and rapid prototyping techniques, allowing for quick iterations based on user feedback. The MR application was developed using the Unity platform, leveraging its robust AR Foundation framework and cross-platform compatibility. We implemented state-of-the-art computer vision algorithms for object recognition and tracking, enabling the system to provide context-aware guidance during daily tasks (Maetzler et al., 2022).

Iterative refinement was carried out through a series of usability tests and focus group sessions with PD patients and healthcare professionals. These sessions provided valuable insights into the ergonomic aspects of the device, the intuitiveness of the MR interface, and the overall user experience. Quantitative data on tremor reduction and task performance were collected using embedded sensors and analyzed using advanced signal processing to assess the system's efficacy. This iterative process allowed us to continuously improve the design, addressing issues such as device weight, grip comfort, and exercise complexity (Ginis et al., 2023).

Throughout the design process, we adhered to ethical guidelines for medical device development and ensured compliance with relevant regulatory standards. The integration of smartphone technology in our system was carefully considered to balance functionality with accessibility, aiming to create a solution that could be widely adopted across diverse socioeconomic backgrounds (Lei and Li, 2024).

By employing this rigorous design research methodology, we have developed a MR-based rehabilitation system that not only addresses the immediate needs of PD patients but also has the potential to evolve and adapt to individual user progress over time. The following sections will delve into the specific design features and technical implementation of our proposed solution, highlighting the innovative aspects that set it apart in the field of neurorehabilitation.

4 DESIGN RESEARCH PROCESS

4.1 Device Mock-up

The development of the hand motion assistance device involved an iterative design process that aimed to provide ergonomic support and tremor stabilization for older individuals with Parkinson's-related tremor disorders. This lightweight device, weighing only 146 grams, was designed with an open-close mechanism to mimic natural hand movements essential for tasks such as grasping and releasing objects. In its resting state, the device maintains an open-hand position that mirrors the palm's natural curvature, allowing users to initiate a grip comfortably and intuitively. When the user grasps an object, the device's embedded servo motor activates to counteract tremors, locking the handles to stabilize the grip and reduce muscular strain during task performance (Figure 1).

To achieve seamless usability, the device was scaled to align with a variety of hand sizes and integrated with components that enable dynamic response to user movement. The servo motor embedded within the thumb component not only facilitates movement but also serves as a stabilizer, providing responsive adjustments that enhance the user's control over hand movements. During the release phase, a button press disengages the servo motor, allowing the device to

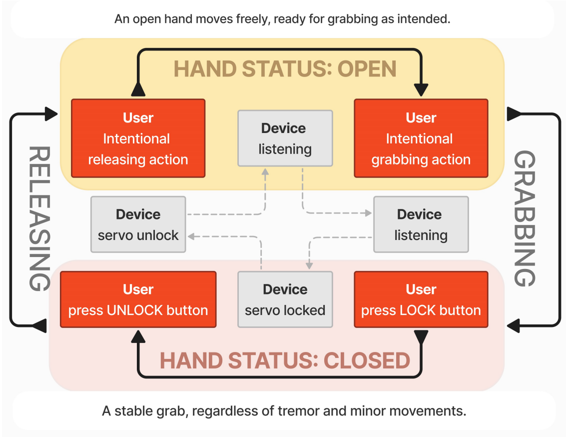

Figure 1: Functional diagram.

return smoothly to the open position. This frictionless transition between gripping and releasing actions minimizes the effort required from users, promoting independence in daily activities by lessening the need for constant grip maintenance (Figure 2).

Figure 2: Iterative design process.

The ergonomic features of the device were refined based on extensive feedback from healthcare professionals and individuals with tremor disorders, who emphasized the importance of both comfort and functionality. The final prototype reflects these insights, incorporating a form-fitting design that supports the hand's natural range of motion and allows for stable, precise hand movements. Additionally, the adaptable mechanism supports a range of tremor severities, providing immediate physical support while allowing users to engage in activities that enhance motor control and dexterity.

4.2 Physical Prototype Design

Ergonomically, the device was designed to conform to the natural contours of the hand, providing intuitive support for daily single-hand tasks such as gripping and releasing objects. Its open-close mechanism mimics natural hand movements, reducing strain and enhancing ease of use. The device accommodates a wide range of hand sizes and tremor patterns, reflecting its adaptability to diverse user needs. Importantly, the design encourages seamless transitions between different hand positions, enabling users to perform tasks independently and with minimal effort (Figure 3).

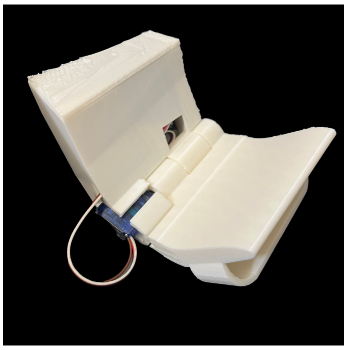

Figure 3: Physical device prototype.

To counteract tremors effectively, the device incorporates a stabilization system that dynamically adjusts to variations in tremor intensity. A servo motor embedded within the thumb component plays a dual role as an actuator and stabilizer, enabling real-time responses to user movements. This feature allows the device to lock securely during gripping actions while maintaining flexibility during release, ensuring both stability and natural motion. The stabilization mechanism is complemented by embedded sensors, including a gyroscope, which track orientation and motion data. This data is transmitted to a MR system, enabling synchronized virtual feedback that supports therapeutic exercises and enhances the overall user experience.

The physical prototype was fabricated using 3D printing technology, ensuring precision and adaptability. The dual-component structure, connected by a hinge, replicates the natural opposition between the thumb and fingers, a critical aspect of effective gripping. The ergonomic design of the prototype mirrors the natural curvature of the palm, providing a comfortable fit that supports stable and precise hand movements. A compact battery, integrated with an Arduino Nano board and low-energy Bluetooth connectivity, powers the device, allowing for lightweight, portable, and wireless operation. These features not only enhance mobility but also enable the potential for telehealth applications, where healthcare providers can remotely monitor and adjust device settings.

Feedback from initial testing sessions with healthcare professionals and users influenced the final design, emphasizing the importance of ergonomic adaptability and mechanical precision. The physical prototype thus provides an effective balance between biomechanical support and ease of use, promoting natural hand movement while addressing the stabilization needs specific to older adults with tremor disorders. By aligning the mechanical structure with natural hand dynamics, this design supports sustained improvements in hand dexterity and user autonomy, reflecting a tailored approach to neurorehabilitation.

4.3 Mixed Reality System

The MR system revolutionizes rehabilitation for Parkinson's patients by combining virtual guidance with physical stabilization on an accessible smartphone platform. This innovative approach leverages familiar, cost-effective technology to deliver adaptive, engaging therapy while broadening access to underserved communities.

The MR system utilizes the smartphone's camera to recognize real-world objects and facilitate interaction. By pointing the camera at items such as books or cups, users activate the "Grab Suggestion" feature. This feature processes successive frames to analyze object attributes, such as dimensions and orientation and provides recommendations for optimal gripping techniques. This functionality supports motor skill rehabilitation by guiding users in adjusting hand positioning and improving object manipulation. (Figure 4)

Figure 4: Smartphone AR interface.

Integrated with the physical prototype, the MR system receives data from an embedded gyroscope that tracks the user's hand movements. This data is processed in real time and displayed as a virtual representation on the smartphone screen. The immediate feedback enables users to adjust their grip strength and hand positioning with precision, fostering improved task accuracy and confidence.

The system's adaptability is a key feature, as it adjusts the difficulty of tasks based on the user's progress. This ensures that rehabilitation remains appropriately challenging and engaging. Gamified exercises further enhance the experience by motivating users to remain consistent in their therapy regimens. The smartphone's familiar interface and ability to evolve through software updates provide an accessible and user-friendly platform for delivering these features.

By leveraging smartphones as the central platform, the MR system offers a cost-effective alternative to traditional MR hardware, which often relies on expensive and specialized equipment. The widespread availability of smartphones, combined with their advanced processing capabilities, allows for broader adoption across resource-constrained and underserved areas. This affordability and scalability make the system particularly impactful for individuals in rural or low-income settings, where access to healthcare technology is often limited.

5 CONCLUSION AND DISCUSSION

The proposed MR-based hand motion assistance device advances neurorehabilitation for Parkinson's disease by integrating physical support with adaptive MR exercises to address tremor management and motor skill improvement comprehensively. This holistic approach combines ergonomic hardware with advanced software, leveraging smartphone technology for accessibility, cost-effectiveness, continuous monitoring, and personalized therapy.

While existing technologies like wearable tremor-suppression devices and VR-based systems show promise, they often lack a complete solution for immediate symptom relief and long-term skill acquisition. Our MR-based system bridges this gap with real-time stabilization, adaptive feedback, and context-aware training. Developed through an iterative design process, the system prioritizes ergonomic comfort, intuitive usability, and therapeutic efficacy. Advanced spatial mapping and object recognition techniques provide context-aware guidance, enhancing skill transfer to real-world activities.

While the initial results are promising, further research is needed to validate the long-term efficacy of our MR-based system in large-scale clinical trials. Future work should focus on integrating smartphone functionality with stabilizers, dual-hand functionality, and exploring the potential for telehealth applications to extend the reach of specialized PD care to underserved populations.

In conclusion, our position paper argues that the convergence of MR technology and ergonomic design has the potential to revolutionize PD rehabilitation. By providing a personalized, engaging, and comprehensive therapeutic experience, our proposed system represents a significant step forward in improving the quality of life for individuals living with Parkinson's disease. As we continue to refine and validate this technology, we anticipate that MR-based rehabilitation will become an integral component of PD management strategies, offering new hope to millions of patients worldwide.

REFERENCES

Arora, S., Baig, F., Lo, C., Barber, T. R., Lawton, M. A., Zhan, A., et al. (2021). Smartphone motor testing to distinguish idiopathic rem sleep behavior disorder, controls, and pd. *Neurology*, 96(1):e78–e89.

Bloem, B. R., Okun, M. S., and Klein, C. (2021). Parkinson's disease. *The Lancet*, 397(10291):2284–2303.

Cipresso, P., Giglioli, I. A. C., Raya, M. A., and Riva, G. (2022). The past, present, and future of virtual and augmented reality research: A network and cluster analysis of the literature. *Frontiers in Psychology*, 13:883546.

Dorsey, E. R., Sherer, T., Okun, M. S., and Bloem, B. R. (2020). The emerging evidence of the parkinson pandemic. *Journal of Parkinson's disease*, 10(s1):S3–S8.

Espay, A. J., Bonato, P., Nahab, F. B., Maetzler, W., Dean, J. M., Klucken, J., et al. (2021). Technology in parkinson's disease: Challenges and opportunities. *Movement Disorders*, 36(3):537–549.

Ginis, P., Nieuwboer, A., Dorfman, M., Ferrari, A., Gazit, E., Canning, C. G., et al. (2023). Feasibility and effects of home-based smartphone-delivered automated feedback training for gait in people with parkinson's disease: A randomized controlled trial. *Parkinsonism & Related Disorders*, 106:105204.

Lei, Z. and Li, X. (2024). Improved grip stability in healthcare: Mixed reality assistance devices for degenerative and age-related hand conditions. In *Companion of the 2024 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '24)*.

Maetzler, W., Klucken, J., and Horne, M. (2022). A clinical view on the development of technology-based tools in managing parkinson's disease. *Movement Disorders*, 37(2):235–246.

Marras, C., Beck, J. C., Bower, J. H., Roberts, E., Ritz, B., Ross, G. W., et al. (2021). Prevalence of parkinson's disease across north america. *Movement Disorders*, 36(1):138–148.

Pahwa, R., Dhall, R., Ostrem, J., Gwinn, R., Lyons, K., Ro, S., et al. (2022). An acute randomized controlled trial of noninvasive peripheral nerve stimulation in essential tremor. *Neuromodulation: Technology at the Neural Interface*, 25(1):112–119.

Wang, B., Shen, M., Wang, Y. X., He, Z. W., Chi, S. Q., and Yang, Z. H. (2023). Effect of virtual reality on balance and gait in parkinson's disease: A systematic review and meta-analysis. *Frontiers in Neurology*, 14:1131656.