Adaptive Augmented Reality Pathfinding for Parkinson's Disease: Integrating Visual Cueing with User-Directed Navigation

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ABSTRACT

Parkinson's disease (PD) affects millions worldwide, with gait impairments and freezing of gait (FOG) episodes representing debilitating symptoms that significantly compromise patient mobility, safety, and quality of life. Recent advances in augmented reality (AR) have demonstrated that visual cueing can effectively modify gait parameters in PD patients, with AR cues proving as effective as real-world cues for improving step length, gait speed, and crossing maneuvers. However, existing AR cueing systems, including applications like Holocue, rely primarily on static, pre-positioned cues or continuous cueing paradigms that require patients to adapt to predetermined patterns, poten- tially limiting patient autonomy and confidence in independent navigation. This paper presents a novel adaptive AR pathfinding system that integrates established visual cueing principles with user-directed navigation to enhance both therapeutic effectiveness and patient autonomy.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 INTRODUCTION

External cueing is a well-established compensation strategy for improving gait and ameliorating freezing of gait (FoG) in people with Parkinson's disease (PD) [6]. Visual cues, such as spatial lines on the ground or body-worn laser projections, have demonstrated superior effects compared to auditory and somatosensory cues due to their stronger coupling with gait and action-relevance [2]. However, existing cueing modalities face practical challenges: physical visual cues are location-bound, body-worn devices have visibility limitations in bright environments, and most solutions lack the flexibility required for tailoring cues to individual user needs and preferences. Augmented Reality (AR) technology offers promising solutions to these limitations by enabling wearable, personalized, and flexible cueing that can project holographic visual cues anywhere, anytime. Recent studies have demonstrated that people with PD can modify their gait to AR cues as effectively as to real-world cues, with state-of-the-art AR headsets overcom- ing previous field-of-view limitations that hindered early implementations [4,5].

Applications such as Holocue have shown that AR visual cueing can provide patient-tailored holographic cues with on-demand activation, demonstrating individual benefits for some users [3]. However, current AR cue systems exhibit a fundamental interaction design limitation: they impose predetermined cue patterns that require users to adapt their intended navigation to the structure of the system rather than supporting the user's own movement intentions. Existing approaches, whether using static prepositioned cues or continuous cueing paradigms, prioritize therapeutic effectiveness over user autonomy, potentially limiting confidence development and independent navigation skills [1,5]. Thus, there is a clear need to enhance AR cueing systems in terms of user agency (supporting rather than dictating navigation intentions), adaptivity (responding to user-selected destinations), and personalization (adjusting to individual movement goals). An emerging approach to address these requirements may be the integration of pathfinding algorithms with established visual cueing principles to create adaptive assistance systems that preserve user autonomy while maintaining therapeutic benefits. The aim of this work is to develop and evaluate an adaptive AR pathfinding system that responds to user-selected destinations while providing contextual visual cueing for people with PD. We implemented an AR system that dynamically generates visual guidance strips based on real-time pathfinding algorithms. The primary objective was to examine whether adaptive visual cueing that follows user navigation intentions can maintain the established benefits of AR visual guidance while enhancing user autonomy.

2 APPROACH

2.1 3.1 Design Rationale and Objectives

The adaptive AR pathfinding system addresses a fundamental limitation identified in existing AR cueing systems: the tension between therapeutic effectiveness and user autonomy. Current systems impose predetermined cue patterns that require users to adapt their navigation intentions to the system's structure, potentially limiting long-term confidence development and independent navigation skills. Our design approach prioritizes collaborative assistance over directive control, where the system supports rather than dictates user movement decisions. The core innovation lies in integrating user-directed destination selection with established visual cueing principles, enabling patients to maintain agency in navigation while receiving contextual therapeutic guidance. Three key design principles guided system development: user agency (preserving patient control over navigation decisions), adaptive response (real-time adjustment to user-selected destinations), and therapeutic continuity (maintaining proven benefits of visual cueing). This approach represents a shift from the one-size-fits-all paradigm toward personalized assistance that responds to individual navigation intentions.

We used the Meta Quest 3, which enables interaction with controllers and passthrough capabilities, that is used to enable Augmented Reality (AR) interaction. To determine the path users point at a desired destination and click the controller to confirm the selection.The first click establishes a locked destination and generates visual guidance, with the headset's projected position onto the floor is used as starting point. Then, cuboids of 15 cm are placed in the floor spaced 75 cm from other's center, corresponding to the average human stride length. The second click enables destination changes while maintaining displayed paths, providing user control without requiring complex gestures or risking accidental navigation changes.

2.2 3.3 Adaptive Pathfinding Integration

The system's primary contribution lies in dynamically generating contextual visual cues based on real-time pathfinding calculations. Unlike static cueing systems that provide predetermined patterns, our approach calculates optimal routes through users' actual environments, accounting for furniture, obstacles, and spatial constraints.

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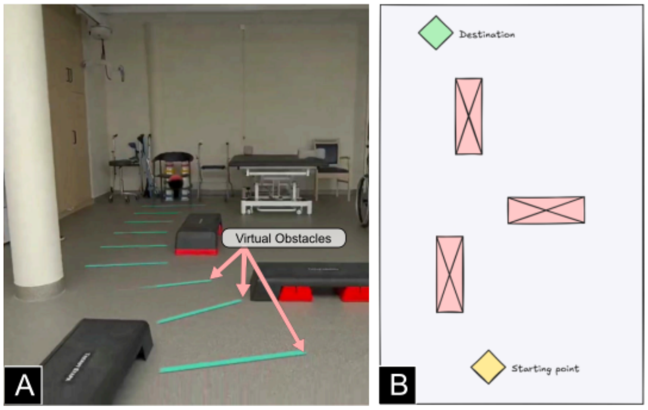

Figure 1: Pilot Study 0verview: (A) Real-world with overlaid obstacles (B) Layout of the pilot study room

The technical implementation uses the Mixed Reality Utility Kit (MRUK) SceneNavigation class, which provides an optimized interface to Unity's NavMesh system specifically designed for Meta Quest platforms. MRUKs scene recognition capabilities automatically generate navigable surface meshes from the Quest 3s spatial mapping data, with the SceneNavigation component handling dynamic obstacle detection and NavMesh generation in real-time. The system generates smooth, curved paths using spline interpolation to avoid sharp directional changes that may be challenging for PD patients. This approach enables personalized guidance that responds to both individual destinations and environmental constraints.

3 Pilot Study

We performed a pilot study to verify the feasibility and efficiency of the prototype. For that, we recruited five participants with confirmed idiopathic Parkinson's disease (Hoehn & Yahr Stage 3) in varying stages with ages varying from 66 to 84 years old. All participants provided informed consent and were tested while they were on medication for the Parkinson disease.

Testing occurred in a controlled 5m × 5m physical therapy room with strategically placed obstacles.Fixed furniture required moderate complexity including turns and obstacle avoidance representative of typical indoor environments. A single marked destination chair was positioned to require navigation from a standardized starting position. We tested three different conditions: (1) natural navigation without assistance, (2) AR pre-computed guidance, and (3) interactive AR navigation. This progression systematically isolated baseline capability, response to visual guidance, and interaction with adaptive pathfinding. We collected subjective feedback on the form of questionnaires and user interviews, where we assessed elements such as efficiency, easy of use and overall considerations about the implemented system which included confidence in path planning, headset comfort, and perceived utility of AR assistance.

3.1 Discussion

The pilot study results demonstrate that adaptive AR pathfinding can maintain the established therapeutic benefits of visual cueing while significantly enhancing patient autonomy through user-directed navigation, with four out of five participants successfully completed the interactive AR navigation protocol. Consistent improvements in navigation efficiency and gait characteristics across participants align with previous findings on AR cueing effectiveness. The participant cohort represented diverse Parkinson's disease presentations, including recent diagnosis with cognitive impairment (P1), dystonia with movement control difficulties (P2), freezing episodes with recurrent falls (P3), classic bradykinetic gait with fatigue (P4), and severe motor impairment 11 requiring walker assistance (P5). This heterogeneity provided insight into how different PD phenotypes respond to adaptive AR pathfinding. Performance patterns revealed distinct response profiles correlating with clinical presentations. Participants with dystonia, freezing episodes, or bradykinetic gait patterns (P2, P3, P4) demonstrated substantial improvements in both navigation efficiency and step characteristics, suggesting that these phenotypes particularly benefit from external visual guidance that bypasses compromised automatic movement control. The most dramatic example was P4, whose characteristic very small parkinsonian steps showed remarkable improvement with visual guidance, reducing step count from 26 to 10 steps while transitioning from small to large step length.Conversely, participants with cognitive impairment or severe motor restrictions (P1, P5) showed more conservative improvements, maintaining stability without dramatic gait modification. P1's inability to complete the interactive condition aligned with her documented cognitive impairment, while P5's consistent medium step performance reflected her severe motor restrictions and daily reliance on walker assistance. Particularly significant was P4's feedback regarding freezing episodes related to his disease, where the system's path selection reduced anxiety around obstacle navigation and decreased his freezing episodes.

4 Conclusion

This pilot study demonstrates that adaptive AR pathfinding can successfully maintain the therapeutic benefits of visual cueing while enabling user-directed navigation for people with Parkinson's disease. Our preliminary study showed that dynamic path planning can indeed assist parkinson users on their therapy sessions. We highlight the use of participants with varying levels of parkinson to support our claims. While our controlled environment demonstrates feasibility, real-world deployment must address challenges including diverse architectural spaces, dynamic obstacles, and varying environmental conditions that may affect AR tracking accuracy. On future iterations of the study, we will include additional quantitative feedback such as step length, gait velocity, and cadence. Further work will provide further insights on more specific metrics of improvemnt based on efficiency and efficacy of the exercise. This research establishes a foundation for collaborative assistance technologies that support rather than dictate user movement decisions.

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