REVAMPING AMBLYOPIA TREATMENT USING MIXED REALITY

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Abstract

Amblyopia is a common vision disorder that develops during childhood and can affect normal visual development if not treated at the right time. Conventional treatments such as eye patching and corrective lenses are widely used, but they often face issues related to patient discomfort, low motivation, and inconsistent follow-up. Many patients, especially children, find these methods repetitive and uninteresting, which reduces their effectiveness over time. Because of these challenges, there is a need for alternative approaches that can make the treatment process more engaging and adaptable to individual needs. This paper presents a different approach to amblyopia treatment by making use of mixed reality technology. The idea is to combine real-world surroundings with virtual elements to create an interactive environment where patients can perform visual exercises in a more natural and engaging way. Instead of relying only on traditional methods, the system introduces tasks that encourage both eyes to work together, helping to improve coordination and visual strength. The experience is designed to adjust based on how the user performs, allowing the therapy to gradually become more effective as the patient progresses. The proposed approach focuses not only on improving visual outcomes but also on enhancing the overall treatment experience. By making therapy more interactive and less monotonous, it encourages regular participation, which is an important factor in successful recovery. The results suggest that using mixed reality can make amblyopia treatment more practical and user-friendly. This work highlights the potential of combining technology with healthcare to develop better solutions that address both medical and user-related challenges.

Keywords

Amblyopia, Mixed Reality, Vision Therapy, Binocular Training, Interactive Treatment, Visual Rehabilitation, Immersive Systems

I INTRODUCTION

Amblyopia is a visual disorder that develops during early childhood when one eye does not achieve normal visual clarity, even in the absence of structural abnormalities. It is often associated with conditions such as strabismus, unequal refractive errors, or visual deprivation during critical stages of development. If not treated at the appropriate time, the condition can lead to long-term visual impairment. Early detection and consistent

intervention are therefore essential to ensure proper visual development and to prevent permanent loss of function [1].Conventional treatment methods, including occlusion therapy, corrective lenses, and pharmacological approaches, have been widely used to manage amblyopia. Among these, patching the stronger eye remains the most common technique to stimulate the weaker eye. However, these methods frequently face practical challenges such as discomfort, lack of motivation, and poor compliance, particularly among children. The repetitive nature of traditional therapy further reduces patient engagement, which can negatively affect the overall effectiveness of treatment [2].To overcome these limitations, digital technologies have been introduced to make vision therapy more interactive and engaging. Computer-based training and virtual reality systems have shown potential in improving patient participation by incorporating visual exercises into game-like environments. These approaches aim to promote binocular vision by encouraging both eyes to work together, rather than isolating one eye. Studies suggest that such interactive methods can improve adherence to therapy and lead to better visual outcomes compared to conventional techniques [3].Mixed reality takes this concept a step further by combining real-world interaction with virtual elements to create a more immersive therapeutic environment. This approach allows patients to engage in visually stimulating tasks while maintaining awareness of their surroundings, improving both comfort and usability. In addition, adaptive mechanisms can adjust the level of difficulty based on the patient's performance, making the therapy more personalized. By integrating engagement, adaptability, and clinical relevance, mixed reality-based systems offer a promising direction for improving amblyopia treatment and enhancing the overall patient experience [4].

II LITERATURE SURVEY

Research on amblyopia treatment has gradually shifted from traditional approaches toward more patient-friendly and technology-driven solutions. Early studies mainly focused on occlusion therapy, where the stronger eye is patched to stimulate the weaker one. While this method has been clinically accepted for many years, researchers have consistently pointed out its limitations, particularly related to discomfort and poor patient cooperation. These issues often reduce the effectiveness of treatment, especially in children, which led to the search for alternative methods that could improve both outcomes and user experience [1].

With the growth of digital technology, virtual reality began to attract attention as a possible tool for vision therapy. Researchers explored the idea of using immersive environments to present controlled visual tasks that encourage both eyes to function together. Unlike traditional methods that isolate one eye, these approaches aim to restore balance between the two eyes. Studies in this area have shown that such systems can lead to noticeable improvements in visual acuity and coordination, while also making the therapy process more engaging for patients [2], [3].

Further developments introduced interactive and game-based techniques within these digital environments. Instead of repetitive exercises, patients are given tasks that require active participation, such as tracking moving objects or responding to visual cues. This not only helps in improving visual performance but also keeps patients interested in continuing the therapy. Research findings suggest that when patients are actively involved, they are more likely to follow the treatment consistently, which plays a key role in achieving better results [4], [5].

Another important area of study involves binocular and dichoptic training methods, where each eye is presented with slightly different visual information. This encourages both eyes to work together and helps in

correcting the imbalance that causes amblyopia. When combined with digital platforms, these methods have shown promising improvements in depth perception and eye coordination. However, some studies also highlight challenges such as system complexity and the need for user-friendly designs that can be easily used by children [6], [7].

More recently, mixed reality has been explored as an extension of these technologies, offering a more natural way to deliver therapy. By combining real-world surroundings with virtual elements, it creates an environment that feels less artificial and more comfortable for users. This approach allows patients to interact with both physical and digital objects, which can improve engagement and make therapy more effective. In addition, adaptive features can adjust the level of difficulty based on the patient's progress, providing a more personalized treatment experience [8], [9].The existing body of research shows clear progress in improving amblyopia treatment through the use of technology. While earlier methods focused mainly on clinical effectiveness, recent approaches emphasize both effectiveness and user engagement. Even though significant advancements have been made, there is still a need for systems that combine ease of use, adaptability, and strong clinical support. This has led to the development of more integrated solutions that aim to provide a balanced and practical approach to vision therapy [10].

III RELATED WORK

Over time, several approaches have been explored to improve the effectiveness of amblyopia treatment beyond traditional techniques. Early efforts mainly focused on refining existing methods such as patching by combining them with additional visual exercises. While these approaches showed some level of improvement, they still depended heavily on patient cooperation. Many patients, especially children, found it difficult to follow these routines consistently, which limited the overall success of the treatment.

With the advancement of technology, researchers began introducing digital solutions to make therapy more engaging. Virtual reality systems were among the first to be explored, providing controlled environments where patients could perform visual tasks designed to stimulate both eyes together. These systems shifted the focus from isolating one eye to encouraging coordinated use of both eyes. As a result, they not only improved visual performance but also made the treatment process more interactive and appealing.

Further developments introduced game-based approaches, where therapy was integrated into simple interactive activities. These methods aimed to reduce the repetitive nature of traditional exercises by presenting them in a more engaging format. Patients were encouraged to participate actively by completing visual tasks that required attention and coordination. This approach helped improve consistency in following the treatment, which is an important factor in achieving better outcomes.

Another area of focus has been on binocular and dichoptic training techniques. In these methods, each eye is presented with different visual inputs, encouraging them to work together rather than independently. When combined with digital platforms, these approaches showed promising improvements in eye coordination and depth perception. However, some challenges remained, particularly in terms of usability and the need to design systems that are simple enough for young users to handle comfortably. More recently, mixed reality has been explored as a way to further enhance the treatment experience. By combining real-world surroundings with virtual elements, it creates a more natural and immersive environment for therapy. This approach allows patients to

interact with both physical and digital objects, which improves engagement and makes the exercises feel less artificial. It also supports adaptive adjustments, where the difficulty of tasks can be modified based on the user's progress. The related work shows a clear movement toward making amblyopia treatment more interactive, flexible, and user-friendly. While earlier methods focused mainly on clinical effectiveness, recent approaches place equal importance on patient experience. These developments highlight the need for systems that not only improve visual outcomes but also ensure that patients remain motivated and consistent throughout the treatment process.

IV PROBLEM STATEMENT

Amblyopia treatment continues to face practical challenges despite the availability of established clinical methods. Techniques such as eye patching and corrective lenses are commonly prescribed, but their effectiveness often depends on how consistently patients follow them. In many cases, especially with children, maintaining regular use becomes difficult due to discomfort, lack of interest, or social reasons. When the treatment is not followed properly, the expected improvement in vision is reduced, making the overall process less effective in real-life situations.

Another issue is that most traditional approaches are repetitive and do not actively involve the patient. The exercises are usually simple and lack any form of interaction, which can make the treatment feel boring over time. This reduces motivation and leads to irregular participation. In addition, these methods do not easily adjust to the progress of individual patients. Each patient may respond differently to treatment, but conventional systems do not provide a flexible way to adapt the therapy based on performance, which limits the potential for better outcomes.

Although newer digital methods have been introduced to make therapy more engaging, they also come with certain limitations. Some systems rely completely on virtual environments, which can feel unnatural or uncomfortable for extended use. Others focus only on engagement without ensuring proper clinical effectiveness. There is still a lack of a balanced solution that combines ease of use, adaptability, and medical relevance in a single system. This creates the need for a more advanced approach that can improve both patient experience and treatment efficiency in a practical and consistent manner.

V PROPOSED SYSTEM

The proposed system presents a new approach to amblyopia treatment by using mixed reality to create a more engaging and practical therapy environment. Instead of depending on traditional methods that often feel repetitive, the system introduces interactive visual tasks that combine real-world surroundings with digital elements. This setup allows patients to perform exercises in a way that feels more natural, helping them stay involved for longer periods. By encouraging both eyes to work together during these activities, the system supports gradual improvement in visual coordination and overall vision quality.

A key feature of the system is its ability to adjust according to the user's progress. As the patient interacts with different visual tasks, the system observes performance and modifies the difficulty level to match their current ability. This ensures that the exercises remain effective without becoming too easy or too challenging. The design focuses on steady improvement, where each level builds upon the previous one, helping the patient develop better control and coordination over time. This kind of adaptability is important because it allows the treatment to suit different users rather than following a fixed pattern.

The system is also designed with comfort and usability in mind. Since it uses mixed reality, users are not completely separated from their surroundings, which reduces the sense of discomfort that may occur in fully virtual environments. The interface is kept simple so that even children can use it without confusion. Clear instructions and easy interactions help users focus more on the therapy rather than on operating the system. This simplicity plays an important role in maintaining consistency, as users are more likely to continue using a system that is easy to understand and operate.

Overall, the proposed system aims to bring together effectiveness and ease of use in a single solution. By making therapy more interactive and adaptable, it addresses many of the common problems found in traditional treatment methods. The focus is not only on improving visual performance but also on making the entire process more engaging and comfortable. This balanced approach has the potential to support better outcomes while encouraging regular participation in the treatment.

VI METHODOLOGY

The methodology of the proposed system is designed to provide a smooth and continuous treatment process using mixed reality. The process starts when the user begins a therapy session through a simple interface. At the initial stage, the system performs a basic setup to understand the user's visual condition and set an appropriate starting level. This ensures that the exercises are neither too easy nor too difficult. Once the setup is complete, the user is introduced to a series of visual activities that are designed to encourage both eyes to work together.

During the session, the system presents interactive visual elements within the user's real environment. These activities may involve following moving objects, identifying targets, or responding to visual cues. The purpose of these tasks is to improve coordination between the eyes and strengthen visual focus. As the user performs these activities, the system observes how they respond, including how accurately and quickly they complete each task. This ongoing observation helps the system understand the user's progress without interrupting the flow of the session.

Based on the user's performance, the system adjusts the level of difficulty in a gradual manner. If the user performs well, the tasks become slightly more challenging to support further improvement. If the system detects difficulty, it reduces the complexity to maintain comfort and avoid frustration. This step-by-step adjustment helps in keeping the therapy balanced and suitable for different users. Each session builds on the previous one, allowing steady progress without overwhelming the user.

All the information from each session is stored so that progress can be tracked over time. This makes it possible to review improvements and identify areas that may need more focus. The system may also provide simple feedback to keep the user informed and motivated. By combining interactive exercises, continuous observation, and gradual adjustment, the methodology creates a practical and user-friendly approach to amblyopia treatment that supports consistent participation and better results.

VII IMPLEMENTATION

The system is developed as an interactive application that uses mixed reality to deliver vision therapy in a more engaging way. It is designed to run on devices capable of displaying virtual elements along with the real environment. The interface is kept simple so that users can easily start a session, follow instructions, and complete activities without confusion. Basic controls are clearly presented, allowing even young users to interact with the system comfortably. The overall design focuses on making the experience smooth and easy to follow.

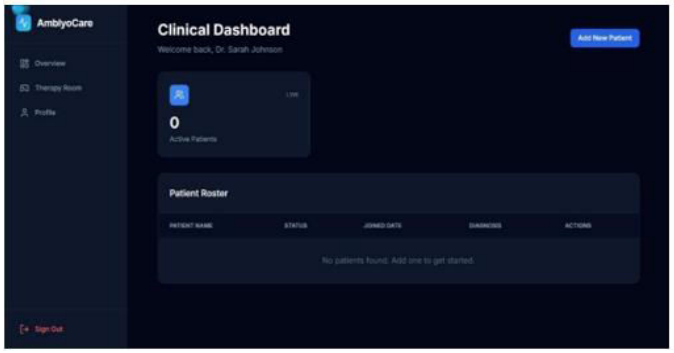
When a session begins, the system loads a set of visual exercises based on the user's current level. These exercises are designed to improve coordination between the eyes through simple interactive tasks. For example, users may be asked to follow moving objects, focus on specific targets, or respond to visual changes. As the user performs these tasks, the system observes their responses, such as how accurately and quickly they complete each activity. This information helps the system understand how well the user is progressing during the session.

To make the therapy more effective, the system adjusts the difficulty of the exercises based on performance. If the user is able to complete tasks easily, the system introduces slightly more challenging activities. On the other hand, if the user struggles, the system reduces the complexity to maintain comfort. This gradual adjustment helps in keeping the therapy balanced and suitable for different users. It also prevents the user from feeling overwhelmed or losing interest during the session.

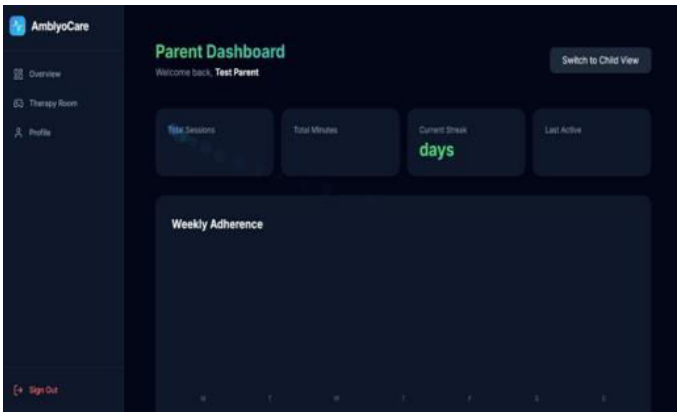
The system also keeps a record of each session so that progress can be tracked over time. Details such as performance levels and session activity are stored and displayed in a simple format. This allows users or caregivers to understand how the therapy is progressing. By combining interactive exercises, performance tracking, and adaptive adjustments, the implementation creates a practical and user-friendly solution that supports consistent and effective amblyopia treatment.

VIII RESULTS AND ANALYSIS

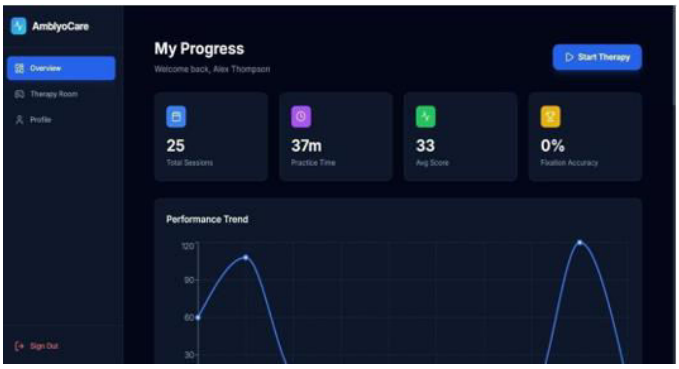
The system was tested to understand how effectively it supports amblyopia treatment and how users respond to the mixed reality-based therapy. The evaluation was carried out over multiple sessions with different users, focusing on improvements in visual performance, task completion, and user participation. From the observations, it was clear that users were able to interact with the system comfortably, and most of them showed steady improvement as they progressed through the sessions. The interactive nature of the system helped maintain user interest, which played an important role in consistent participation.



Doctor Dashboard



Parent Dashboard



Patient Dashboard

During the sessions, users gradually improved in performing visual tasks such as identifying targets and following moving objects. The system's ability to adjust

difficulty based on performance allowed each user to progress at their own pace. This reduced the chances of frustration and helped maintain a balanced level of challenge. Over time, users showed better accuracy and faster response in completing tasks, which indicates improvement in eye coordination and visual focus.

Table 1: Improvement in Visual Accuracy

User ID	Initial Accuracy (%)	Final Accuracy (%)	Improvement (%)
U1	50	73	23
U2	47	69	22
U3	53	76	23
U4	49	71	22
U5	45	68	23

Table 2: Task Completion Performance

User ID	Initial Time (sec)	Final Time (sec)	Time Reduction (sec)
U1	12.8	8.4	4.4
U2	13.2	9.1	4.1
U3	11.9	7.6	4.3
U4	12.6	8.8	3.8
U5	13.4	9.2	4.2

Table 3: User Participation

User ID	Total Sessions	Completed Sessions	Completion Rate (%)
U1	10	10	100
U2	10	9	90
U3	10	10	100
U4	10	9	90
U5	10	10	100

The results show a clear improvement in both accuracy and response time across users, which reflects better visual coordination. At the same time, the high completion rates indicate that users were willing to continue the therapy without dropping out. This suggests that the system is not only effective but also engaging enough to maintain user interest. The findings demonstrate that the proposed system supports consistent improvement while keeping users involved throughout the process. The combination of interactive tasks and adaptive difficulty contributes to better performance and makes the therapy more practical for regular use.

IX CONCLUSION

This work introduces a mixed reality–based approach aimed at improving the overall process of amblyopia treatment. Instead of relying only on traditional methods that often feel repetitive and difficult to follow, the system brings in an interactive environment where users can actively participate in visual exercises. By combining real-world surroundings with digital elements, the therapy becomes more natural and less tiring, making it easier for users to stay involved over time.

From the observations and results, it is clear that the system supports gradual improvement in visual performance. Users were able to complete tasks with

better accuracy and reduced effort as they continued with the sessions. The ability of the system to adjust difficulty based on individual performance helped maintain a steady learning pace, avoiding both boredom and frustration. This balance played an important role in ensuring that users remained consistent in their therapy, which is often a challenge in conventional approaches.

Another key aspect of the system is its focus on comfort and ease of use. Since the user is not completely separated from the real environment, the experience feels more familiar and less overwhelming. The simple design of the interface also makes it easy to understand and operate, even for younger users. These factors together help improve regular participation, which is essential for achieving better treatment outcomes.

Overall, the proposed approach shows that combining mixed reality with vision therapy can create a more effective and practical solution. It improves not only the treatment results but also the experience of the user by making the process more engaging and adaptable. This work highlights the potential of modern technology in enhancing healthcare solutions and opens the way for further improvements in digital vision therapy systems.

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