GAME-BASED PHYSICAL THERAPY USING AUGMENTED REALITY AND BODY TRACKING FOR CHILDREN'S FRACTURE RECOVERY

Amal Abdulaziz Al-Rasheed, Amal Nasser Aldosari, Reema Fahad Alharthy, Dena Adel Alfaiz and Shatha Ibrahim Almalki

Department of Information Systems, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

ABSTRACT

Temporary disabilities, such as leg and arm fractures, are common injuries among children, requiring physical therapy sessions after the casts are removed. However, children struggle to adhere to these sessions, as they quickly get bored with traditional exercises, and the high cost of therapy sessions can affect the continuity of treatment. Mareen offers a solution to these challenges with an innovative digital game that transforms physical therapy into an interactive experience. The game uses augmented reality, body tracking, and rule-based programming to provide interactive sessions and instant feedback on the child's performance. With today's generation accustomed to using devices, incorporating therapy with fun elements and a points-based reward system where a child completes all the exercises and an egg hatch to reveal a cute animal will effectively motivates children to stay engaged and adds excitement with a sense of achievement to their therapy journey.

KEYWORDS

Fractures, Augmented Reality, Body Tracking, Rule-based Programming, Gamification

1. INTRODUCTION

Leg and arm fractures are common injuries among both adults and children, with a particularly high prevalence in the latter due to their adventurous nature, often leading to accidents. A study conducted at King Abdullah Specialist Children's Hospital in Saudi Arabia found that leg and arm fractures account for 10-25% of all paediatric cases [1]. While these injuries can be painful, they are generally manageable with consistent physical therapy.

Physical therapy is essential for effective recovery following a bone fracture. It is the most effective method for restoring the normal range of motion, strength, and functional mobility, often serving as an initial step in the healing process. However, adherence to physical therapy sessions can be a challenge. Many individuals, particularly children, may find frequent visits to therapy clinics tedious, and some may have limited access to these services [2].

To bridge this gap, technology can play a pivotal role in enhancing the effectiveness and accessibility of physical therapy [3]. It has the potential to overcome both social barriers, such as

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difficulties in accessing treatment, and physiological barriers, including issues related to sensory processing during therapy sessions. The COVID-19 pandemic underscored this potential by disrupting traditional therapy practices and prompting the adoption of remote care solutions. Current modalities of rehabilitation include both supervised and unsupervised exercises, but advances in technology are opening new horizons in this field. Virtual reality (VR), augmented reality (AR), gamification, and telerehabilitation are appealing for orthopaedic patients' rehabilitation [4], [5].

Augmented reality, in particular, is an innovative technology that overlays digital content onto the real world, enriching users' perceptions of their environment without replacing it [6]. Typically accessed through smartphones, tablets, or smart glasses, AR does not require specialized equipment. This technology transforms rehabilitation exercises into interactive games, creating immersive environments that capture children's attention and actively involve them in their recovery process. Coupled with body tracking technology, therapists can monitor movements in real-time, ensuring exercises are performed accurately and optimizing recovery outcomes [7]. Research indicates that AR can enhance patient motivation and improve physical outcomes by making the rehabilitation experience more enjoyable and interactive [8].

The application of augmented reality (AR) in motion rehabilitation has garnered significant attention in recent years, showcasing its potential to enhance therapeutic outcomes across various patient populations. One notable approach is presented in [9], which emphasizes the use of wearable technology to provide immediate feedback during rehabilitation exercises. This system aims to improve patient engagement and adherence by allowing users to visualize their movements and receive corrective feedback in real time, ultimately enhancing motor learning.

Additionally, a dissertation [10] explored how integrating human interaction and biofeedback mechanisms can further improve rehabilitation outcomes. By creating a more interactive rehabilitation environment, this system aimed to foster a more engaging experience for patients, thereby increasing motivation and compliance.

The psychological impacts of AR in rehabilitation are also highlighted in [5]. This study suggests that AR can alleviate anxiety and improve overall satisfaction, which are critical components for successful rehabilitation. By combining AR with gamification elements, rehabilitation becomes a more enjoyable experience, encouraging patients to participate actively in their recovery.

Specific applications of AR technology are exemplified in [11], which focuses on the rehabilitation of fine motor skills. The findings indicate that AR can significantly facilitate the recovery of hand functions in patients, demonstrating its effectiveness in targeted therapeutic interventions. Similarly, [12] presents promising results in improving balance and coordination among older adults, highlighting the adaptability of AR technology for different demographics.

The effectiveness of AR in gait rehabilitation is illustrated in [13], which showcases improvements in gait patterns for stroke patients through interactive AR sessions. This case report reinforces the notion that AR can provide valuable feedback to patients, facilitating more effective rehabilitation.

Moreover, the role of gamification in rehabilitation is explored in [14], where the integration of game elements into rehabilitation exercises significantly improved patient motivation and outcomes. Similarly, [15] demonstrates AR's capacity to enhance functional recovery in paediatric populations, thereby broadening the scope of AR applications in motion rehabilitation.

In summary, the growing body of research highlights the multifaceted benefits of AR in motion rehabilitation, including enhanced patient engagement, improved motor function, and positive psychological impacts. As these technologies continue to evolve, AR stands poised to significantly transform rehabilitation practices across various settings and patient populations.

This paper explores the potential of AR and body tracking in the rehabilitation of children with fractures. Through innovative practice, we introduce our solution, "Mareen" a game-based physiotherapy application designed specifically for children with fractures. Mareen application integrates AR-guided 3D exercises with advanced motion tracking and real-time feedback mechanisms, transforming traditional physiotherapy into engaging interactive experiences. This approach aims to enhance children's motivation and engagement throughout their rehabilitation journey.

The paper is structured as follows: Section 2 outlines the methodology employed in the study. Section 3 presents a comprehensive discussion of the findings. Section 4 offers recommendations and highlights the expected outcomes. Finally, Section 5 concludes the paper and explores avenues for future work.

2. METHODOLOGY

2.1. System Overview

The proposed system, Mareen, is a game-based application designed to enhance the physical therapy experience for children with arm or leg fractures. It integrates Augmented Reality and Body Tracking to provide interactive therapeutic exercises, ensuring children perform their exercises accurately and effectively.

One of the main challenges in traditional physical therapy is that patients may struggle to perform home exercises correctly after receiving instructions at the clinic, potentially leading to incorrect movements that hinder recovery. Mareen addresses this by utilizing body tracking technology to monitor and analyse movements in real time. Using the device's camera and frameworks like ARKit, the system tracks key joints, extracts movement data, and evaluates performance through rule-based programming.

To ensure children perform exercises correctly, Mareen provides real-time feedback by detecting incorrect postures and movements, then offering pop-up alerts for correction. This immediate notification helps children adjust their movements without requiring constant supervision.

In addition to tracking and feedback, Mareen integrates a rewards and motivation system, encouraging children to remain engaged by earning rewards for completing exercises correctly. This gamified approach makes the therapy process enjoyable and motivating, ensuring that children stay committed to their rehabilitation.

By combining augmented reality, body tracking, and real-time feedback, Mareen enhances children's exercise performance, provides a more engaging and interactive therapy experience, reduces the need for direct medical supervision, and accelerates recovery in a safe and effective manner, making the rehabilitation journey more accessible and enjoyable for children.

2.2. System Architecture

Figure 1 shows the system architecture of the proposed system. The system is composed of five phases: camera calibration setup, tracking, registration, feedback, and composition.

1. Camera calibration setup: At this phase, the iPad camera is the primary instrument for photographing real-world scenes. To ensure optimal performance, the camera and its surroundings must be appropriately calibrated and configured for application use. This involves checking the camera settings and making sure the lighting is acceptable.

2. Tracking: In this phase, 3D tracking is enabled, and ARKit is used to generate augmented reality, allowing for accurate recognition and analysis of body joints and motion to efficiently monitor the child's movements.

3. Registration: In the registration phase, interaction between virtual and natural objects and setting up the virtual scene with Unity. Hence, the smooth transition and synchronization of movements will become synchronized between the child's body and different points of interaction between their movements and virtual objects.

4. Feedback: This phase provides instant feedback to the child about his performance during the exercises, through text signals, and a points evaluation system. This aims to motivate the child, correct mistakes, and improve the quality of performance.

5. Composition: In this final step, the child's tracked motions, virtual objects, and real-world camera feed are integrated to form a seamless, augmented scene. This stage delivers an integrated experience by allowing the virtual and physical elements to interact dynamically in real-time and providing immediate feedback on the child's session performance.

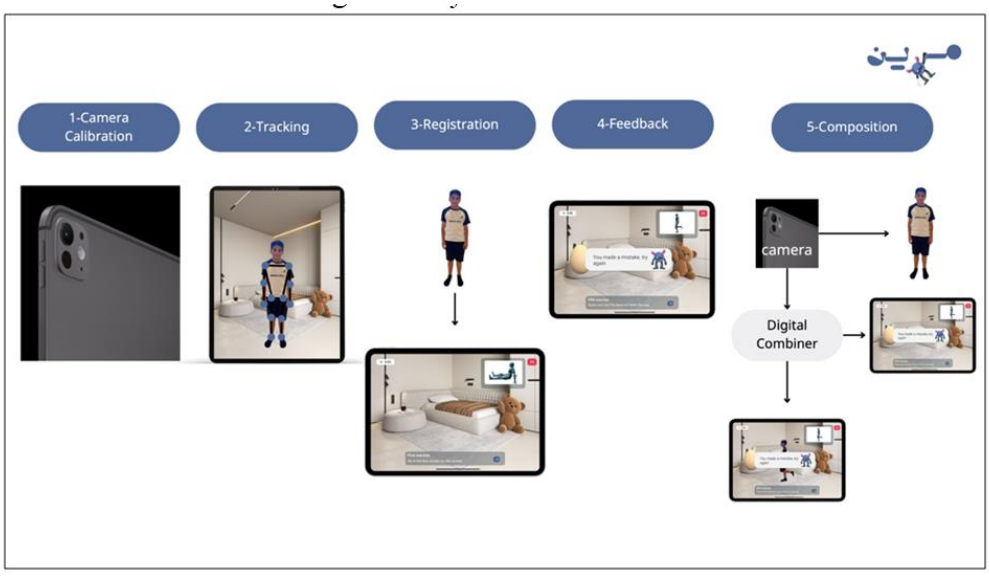

Figure 1. System Architecture

2.3. System Analysis

During the system analysis process, the focus was on exploring the requirements for the comprehensive development of Mareen game, considering how all components work within the

system environment. This analysis formed the basis for the design and development of the next phases of the project to ensure that the needs of users are effectively met.

To better understand the needs and challenges of the target group, a questionnaire was used as a key data collection tool. The questionnaire targeted parents of children who suffered arm or leg fractures, with the aim of evaluating the effectiveness of digital games in motivating children to adhere to physiotherapy sessions. The questionnaire, which included four closed questions and three open-ended questions, collected a total of 202 responses. The results showed great support for the idea of the game, confirming the need for an innovative solution such as “Mareen”.

Interestingly, 93.1% of participants indicated that they had not used a similar application or toy that would help their children adhere to physiotherapy sessions before, showing a large gap in the market. This in turn confirms the importance of Mareen game as an innovative solution and a race in this field. Overall, the survey results showed that the game will address common challenges such as lack of motivation and interaction, by providing a fun and inspiring therapeutic experience for children.

To enhance the understanding of these challenges, an online interview was conducted with a paediatric physiotherapist, who specializes in fracture cases. The specialist provided valuable insights into the challenges faced by traditional treatment for children. He explained that children often feel discomfort or fear in medical environments, which affects their participation. He stressed the importance of building a relationship of trust between the child and the therapist, because dealing with children requires a completely different approach than dealing with adults.

When discussing the integration of augmented reality technology, the specialist expressed his great optimism, stressing that this technique can make a big positive difference in motivating children compared to adults. He pointed out the importance of including stages and levels within the game to create a sense of achievement to the child, while offering rewards such as points or badges to motivate them to continue. The specialist stressed that augmented reality technology will significantly improve the quality and experience of physiotherapy for children.

As shown in Figure 2 The flowchart illustrates the main process of the Mareen system, showing how the child interacts with the physical therapy exercises and how the system responds to their performance.

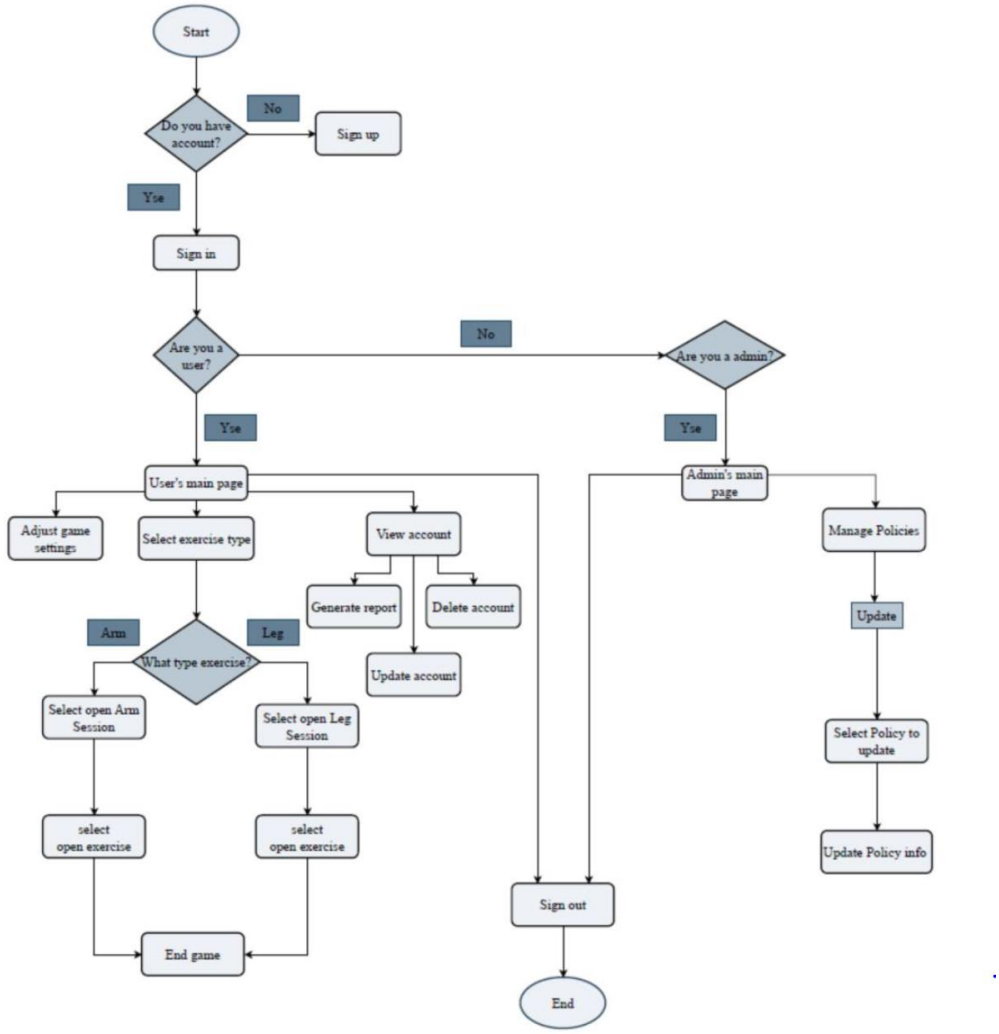

Figure 2. Flowchart diagram

2.4. System Implementation

The development of Mareen game involves various hardware and software requirements, including:

- Microsoft word, used for documentation
- Discord, Social platform used for meetings and communication
- Trello, platform used for Project management and monitoring team progress
- Figma, Collaborative web application used for Interface Design
- XCode, Integrated Development Environment (IDE) used to develop software
- CloudUI, cloud-based user interfaces for applications
- Firebase, a database hosted on the cloud
- ARkit, Creating augmented reality (AR) experiences
- Unity, Game development
- Personal computer (MacBook Pro with processor 3.1 GHz dual-core Intel Core i5, and 8 GB of RAM) Utilized for documentation, design, and application development.
- iPad (iOS iPad with 64 GB Storage Capacity and 6 GB of RAM) for testing

- Hard Disk Drive (HDD with 1TB) for storing data

The architectural design relies on three interconnected layers starting with the presentation layer that focuses on the user interface and the interaction experience. Unity is used to develop the graphical interface and integrate technologies such as ARKit, which provides the augmented reality environment and body tracking capabilities to enable real-time movement tracking. This layer displays the content, collect user inputs and provide instant visual feed, followed by the business layer, which is the beating heart of the system. It manages requests from the presentation layer and implements the logic of the application based on the C# programming language in Unity to create a logic that coordinates processes and ensures the smoothness of data flow between the layers and finally the data layer that manages and stores data using Firebase to ensure that user data is saved, secure and organized and supports application performance by providing the necessary data for user interactions. These layers work together to provide an integrated and seamless experience in Mareen [16].

2.5. Prototype

The interface ofMareen game was carefully designed to be suitable for children and to encourage them to stay committed to their physical therapy sessions. In this paper, we present the interface in English for demonstration purposes, while the primary language of the game is Arabic.

We ensured that every screen contained the fun, vibrant colours that make an exciting and friendly fun experience for children. Adding large interactive buttons assists in navigation for younger users with smaller hands, they are easier to use. We used illustrative images in conjunction with simple language and directions to help ease the user in understanding the tasks required of the user.

We also included elements of fun inside the game, such as the idea of “eggs” to provide an extra fun element to the experience. Each surprise inside the eggs heightens the curiosity of children and compels them to continue with the game, which makes it a form of entertainment in itself. This element is important in making it fun for children and motivates them to do the movements and complete the physical therapy exercises. In Figure 3 we show welcome and sign-up screens.

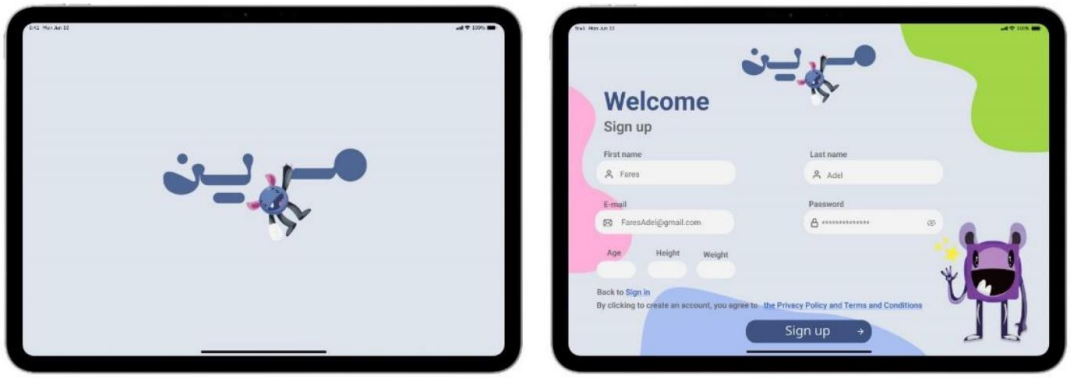

Figure 3. Welcome and sign-up screens of Mareen.

The initial screen in Figure 4 appears when the user selects the character screening button located at the main interface. This indicates to the user that they need to select a character to use for encouragement. The user can scroll through the characters available by clicking the arrows. Once

the user selected a character, they can click "Start Playing" which allows them to begin an entertaining and motivating physical therapy experience with Mareen application.

The second screen in Figure 4 showcases the homepage, designed for user-friendliness and clarity. It prompts users to indicate whether they have a broken arm or leg, allowing for a tailored service. On the right side of the interface, key elements such as the homepage, account settings, and logout options are easily accessible, facilitating smooth navigation and enabling users to meet their needs effortlessly. Additionally, a character selection button is available, and the top right corner displays the user's earned points, which are visible across all interfaces. These points serve as a motivational tool, enhancing user engagement and interaction with the game.

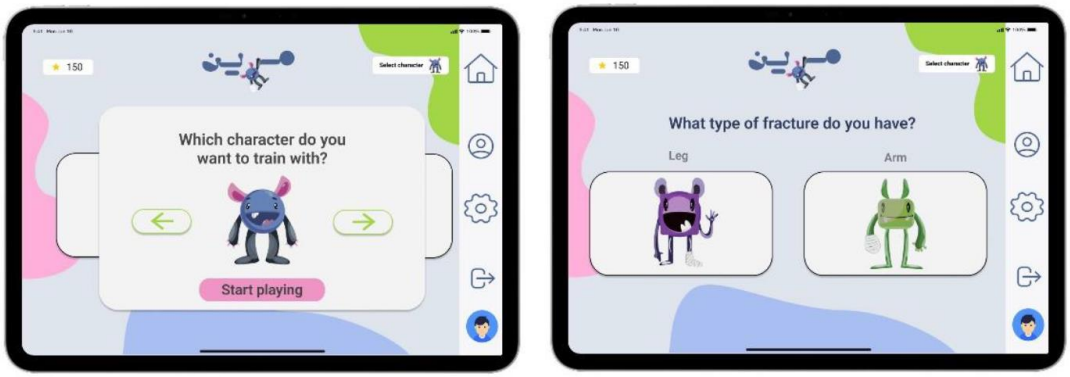

Figure 4. Start screens of Mareen

The first screen in Figure 5 depicts the sessions interface, featuring large, clear icons that represent the number of weeks of sessions. The initial session is accessible, while the subsequent sessions remain locked. Users can progress to the next session only after successfully completing the exercises in the current one.

The second screen in Figure 5 presents the exercises interface, which consists of five exercises corresponding to each day. The first exercise is available, and users must complete it correctly before they can advance to the next exercise.

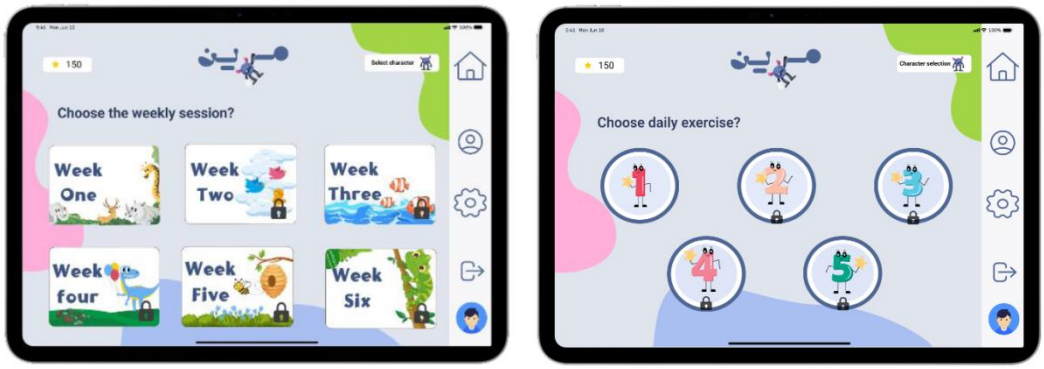

Figure 5. Session and Exercises Interface.

Figure 6 showcases Mareen application, which begins with an augmented reality environment interface featuring a character in the upper left corner to guide the child. The time displayed in the upper right corner indicates how long the child has spent on the exercise. At the bottom of the

interface, a rectangle provides instructions and shows which exercise the child is currently performing.

In the initial step of any exercise, a yellow square appears to indicate where the child should position themselves, whether sitting or standing. As the child engages in their physical therapy journey, the experience evolves into an exciting adventure. They first see an egg in the augmented reality interface and are prompted to move their leg forward and backward—performing a physical therapy exercise—until the egg hatches and an animal emerges. This interactive method makes physical therapy both engaging and enjoyable.

Upon completing each exercise, a pop-up interface appears to encourage the child to continue with the remaining exercises. This interface features a cheerful character celebrating their achievement and displaying the star earned for completing the exercise. If the child performs any exercise incorrectly, a pop-up message will alert them and prompt them to try again. In the fifth exercise, the child is instructed to raise and lower their leg to hatch the egg and reveal the animal. After successfully completing this exercise, the child will receive their first animal. At any point, the child can exit the game by clicking the red X located on the left side of the interface.

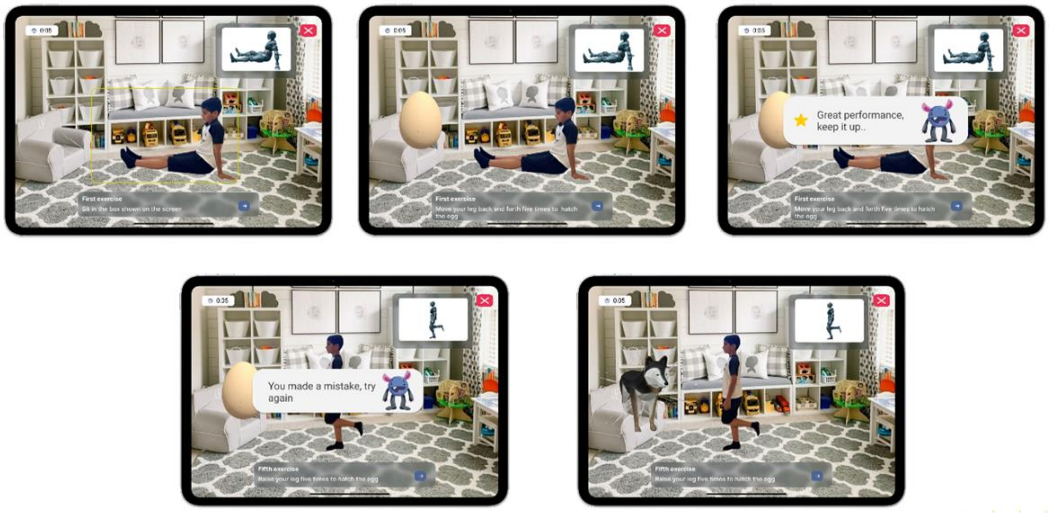

Figure 6. Game Interface

Figure 7 depicts the results interface that appears after the child has completed all the exercises. This interface displays the total number of stars earned, the points accumulated, and the time taken to finish all five exercises. By clicking the arrow on the left side of the interface, the user can return to the exercises interface.

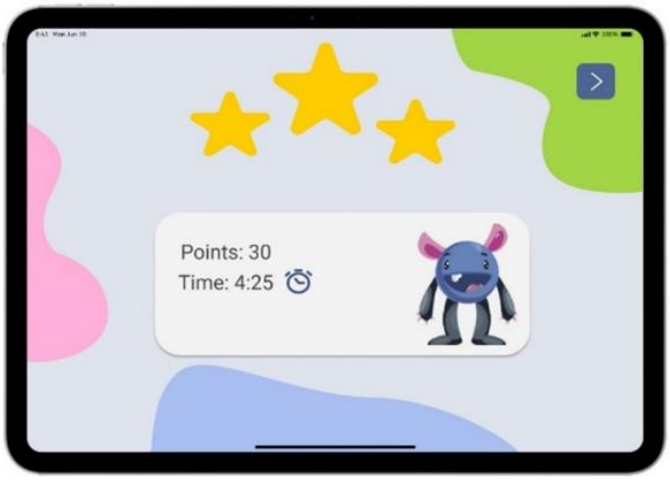

Figure 7. Result interface

3. DISCUSSION

The integration of game-based physical therapy using augmented reality and body tracking represents a transformative shift in the rehabilitation landscape for children recovering from fractures. This approach not only addresses the physical needs of young patients but also engages them in an interactive and enjoyable manner, which is crucial for maintaining motivation during recovery. The findings indicate that children are more likely to adhere to their rehabilitation protocols when therapy is gamified, as it turns a potentially monotonous process into an adventure. Furthermore, the use of body tracking technology allows for real-time feedback, enabling personalized exercise adjustments that can enhance effectiveness and reduce the risk of reinjury. However, challenges remain, including the need for extensive user testing to ensure that the technology is accessible and user-friendly for all children, regardless of their technical proficiency. Additionally, considerations around screen time and its impact on children's health must be addressed, ensuring that the benefits of interactive therapy do not come at the expense of overall well-being. Overall, this innovative approach holds great promise for improving recovery outcomes and should be further explored and refined to maximize its potential in pediatric rehabilitation.

4. RECOMMENDATIONS AND EXPECTED OUTCOMES

Today's children are of the digital generation, and the majority are aware of the usage of tablets, smartphones, and interactive software. After natural exposure to technology, the implementation of interactive physical therapy tools such as the Mareen app, provided at home after cast removal to the children, as an aid device for both physical and psychological recovery, is recommended. These kinds of solutions have the ability to significantly increase children's compliance towards therapy sessions by transforming repetitive, normally monotonous exercises into enjoyable and fun activities. With immediate corrective guidance and prompt feedback, children are encouraged to perform exercises correctly, which results in faster recovery and increased therapeutic efficiency. Furthermore, replacing the clinical setting with an entertaining, engaging environment can also remove the boredom and stress experienced by most children, thus enhancing rehabilitation to become more enjoyable and rewarding.

Secondly, home-based measures reduce the necessity for subsequent visits to a clinic, costs borne by families, and guarantee an appropriate and effective resource present for the children who

remain far from specialized facilities. To date, Mareen is the prototype of how mobile technologies have revolutionized the delivery of paediatric rehabilitation as a more affluent, accessible, and savvy process.

5. CONCLUSIONS AND FUTURE WORK

This paper introduced a game-based physical therapy designed to help children recover their hand and leg functions after fractures. The system, called "Mareen," features an engaging digital game that makes physical therapy fun and accessible. By using augmented reality, body tracking, and simple programming rules, it provides interactive therapy sessions and gives immediate feedback on how the child is doing. This effort supports research focused on using technology to develop practical and effective medical solutions.

In future, we plan to add the following features to Mareen game:

First, we aim to diversify the exercises beyond just arms and legs to include all body parts targeted by physical therapy. This expansion will provide a more comprehensive therapy experience for children.

To enhance technology integration, we will introduce artificial intelligence to track the child's progress and provide personalized feedback. Additionally, we will optimize motion tracking accuracy to ensure the system can detect and monitor movements with much greater precision, offering smoother user experience. The game will also be translated into multiple languages to reach a wider audience, and we will develop support for the Android system to increase device compatibility.

To boost engagement, we will enhance the reward system by allowing children to collect animals and add them to a virtual farm. To make the game more visually appealing, we will introduce a variety of themes. Instead of relying solely on the egg as the main element from which the animals emerge, we will add bubbles that float and burst to reveal the collected animals, accompanied by dynamic visual and audio effects.

Furthermore, we aim to enhance social interaction and collaboration within the game. A multiplayer mode will be introduced, allowing children to perform exercises together in an augmented reality (AR) environment, which will motivate them and increase engagement. A family cooperation system will also be developed, enabling parents or siblings to participate in therapy sessions—either by encouraging the child or exercising together with them.

To further promote motivation, we will introduce a global ranking system. This feature will allow children to see their ranking among other players based on their progress and success in exercises. By fostering a sense of competition, this system will encourage children to stay committed to their therapy sessions, making the experience more stimulating and engaging.

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AUTHORS

Amal Al-Rasheed: Dr. Amal Al-Rasheed is an associate professor at the department of Information Systems, College of Computer and Information Sciences, Princess Nourah Bint Abdulrahman University (PNU), Riyadh, Saudi Arabia. She got her PhD degree in Information Systems from King Saud University in 2017. Amal’s research interests focus on education, knowledge management, data mining, data analytics, cyber security, and natural language processing. She has been involved in many projects related to learning technologies, cyber security, and virtual reality. Her contributions in research projects in academia led to the publication of papers in many journals and conferences. In 2017, she was awarded the Research Excellence Award, by PNU, for her publications during performing PhD.

Reema Alharthy is a recent graduate from the Department of Information Systems, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University (PNU), Riyadh, Saudi Arabia. Her research focuses on digital health, digital transformation, and new technologies. Throughout her academic career, she displayed leadership by leading PNU's Information Technology Club and was awarded a certificate of excellence in leadership. She successfully arranged a technical bootcamp and a specialized workshop, which helped students improve their information technology skills. She successfully

arranged and evaluated a technical bootcamp and a specialized workshop, which helped students improve their information technology skills.

Reema'smajor accomplishments include winning the Farmathon hackathon hosted by King Saud University and completing a training program at the Nuclear and Radiological Regulatory Commission, where she was responsible for managing and supporting digital transformation projects. She is passionate about leveraging technology to create innovative solutions that positively impact society and advance digital projects.

Dena Alfaiz graduated in 2025 from the Department of Information Systems, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University. Dena's research interests include digital solutions, emerging technologies, innovation in information systems, digital transformation, and the application of technology across various sectors such as healthcare, education, and business. She contributed to the development of "Mareen," an AR-based rehabilitation game, which received a first-place award at a major hackathon event.