mARble-run: Fun within Hand's Reach

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Abstract

Augmented reality (AR) technology has reshaped gaming by offering players immersive experiences that merge the virtual and physical worlds. In this paper, we present a simple and intuitive AR marble game designed for the Magic Leap 2 device. The game allows players to effortlessly draw custom tracks in three-dimensional space using the Magic Leap controller and place a marble that travels along these paths based on realistic physics, powered by the Unity physics engine. Using Magic Leap 2's advanced AR capabilities, mARble-run creates a seamless and engaging environment where players can interact with the world around them in real time. Results from a user study demonstrated high levels of satisfaction and ease of use, with participants particularly praising the intuitive controls and engaging gameplay. We discuss the technical framework, focusing on track generation around the drawn path. The paper concludes by exploring the game's potential applications in entertainment and education, where its simplicity and realism can be used to engage users and facilitate learning in an interactive, hands-on way.

1. Introduction

Augmented reality (AR) has become a key technology in the transformation of how digital content interacts with the physical world, offering innovative experiences in entertainment, education and beyond [7, 9]. In AR gaming, the ability to create realistic and engaging interactions between virtual objects and the real environment presents both opportunities and challenges [6]. Despite many advances in AR, creating games that strike the right balance between simplicity, intuitive controls, and realistic simulations remains a difficult task. Existing AR games often require complex interactions or steep learning curves, which can limit accessibility and engagement [8].

In this paper, we introduce a simple yet intuitive AR marble game developed for the Magic Leap 2 device [4]. *mARble-run*[1] allows players to draw custom tracks in three-dimensional space using the Magic Leap 2's controller, while marbles follow these paths with realistic, physics-based movement, powered by the Unity [10] physics engine. The use of the Magic Leap 2 device enables precise spatial tracking and seamless integration of virtual elements into the real world environment, offering players a highly immersive experience. The game's design focuses on ease of use, allowing players of all ages and experience levels to quickly understand the mechanics and enjoy creating and modifying tracks in a hands-on, interactive way.

We describe the technical aspects of the game, including the integration of Unity's physics engine for realistic marble behavior, as well as how the abilities of the MagicLeap 2 device, such as plane detection, enhance the gameplay experience. In addition, we explore potential educational applications of the game, particularly in the context of teaching basic physics concepts through interactive play. The paper concludes by discussing future directions for the game, including the possibility of adding multiplayer functionality and expanding the scope of its educational uses.

2. Related Work

The intersection of AR and interactive gaming has gained significant attention in recent years, with various studies exploring how AR can enhance user experience through immersive and interactive environments. The specific concept of a physics-based marble game in AR, where users can draw tracks and observe objects interacting with them according to realistic physical laws, draws from multiple research areas: AR games, simulation of physics in games, and user interaction with virtual objects.

2.1. Augmented Reality Gaming

AR has become increasingly popular in gaming, offering immersive experiences that blend virtual elements with the real world. Recent developments have shown a growing interest in physics-based AR games, which provide engaging

[1] Implementation at https://github.com/EdoardoNegri/mARble-run

Figure 1. An example track created in mARble-run on the Magic Leap 2. This track showcases various potentials of the game, including flexible paths and different special blocks.

and interactive gameplay. These games leverage the capabilities of modern game engines, such as Unity3D, which offers built-in NVIDIA PhysX physics engine support for realistic physics calculations [3].

2.2. Drawing and Interactivity in AR Games

The idea of user-generated design within AR, particularly drawing and interacting with virtual elements, is not new. In the context of AR, draw-and-place mechanics have been explored in various games and applications. For example, Tilt Brush [1], an AR/VR painting app, provides users with the ability to create 3D drawings in virtual space. However, this application focuses more on artistic expression, rather than on the specific application of physical interactions, such as having a marble roll along a user-defined track.

2.3. Realistic Physics in AR

Physics simulation is crucial to creating an engaging and believable user experience in AR environments. Recent advances in AR physics engines, such as Unity's AR Foundation [11] and Google's ARCore [2], provide robust tools to simulate realistic physics in AR games. In particular, the incorporation of real-time physics-based interactions, including gravity, collisions, and friction, is critical for applications involving moving objects like marbles.

3. Methodology

Upon launching the app, the user is presented with a view of the physical space, complemented by a floating store panel beside them. The store offers a variety of components, including the marble, which can be spawned by selecting their corresponding images. From this interface, users can either design new marble track segments, add special blocks or marbles, or erase existing elements using intuitive actions with the controller.

Objects and track segments are automatically connected when placed in close proximity to one another. Additionally, physical surfaces such as tables or the floor can be seamlessly integrated into the track, leveraging Magic Leap's plane detection capabilities.

The Magic Leap Controller is used for interaction instead of hand gestures, as this approach provides greater stability. Users often extend the track path beyond the camera view of the glasses, and using a button press helps to maintain a more reliable and consistent experience.

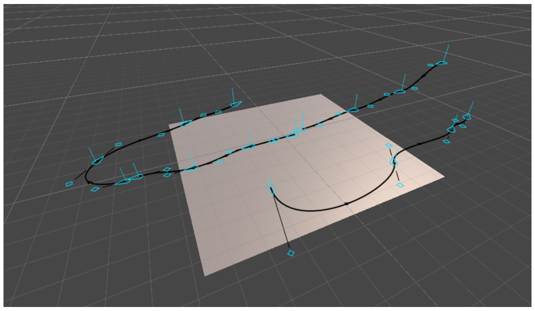
3.1. Track Generation

The user can create a track segment using the Magic Leap Controller. While holding the bumper button, the controller's position is recorded at each frame along the desired path. These recorded points are used to generate a Bézier curve that smooths the trajectory of the track. The Bézier curve is then sampled at intervals determined by the desired track width. At each sampled point, vertices for the track's cross-section are calculated and oriented along the direction of the curve. The vertices from each point are then connected to the corresponding vertices of the next point, forming the geometry of the track segment. Finally, the mesh is closed off at both endpoints to complete the segment. Once the segment is defined, a Mesh Collider is automatically generated to enable physical interactions with the marble. An example of the drawn splines and the resulting meshes created from them can be seen in Fig. 2.

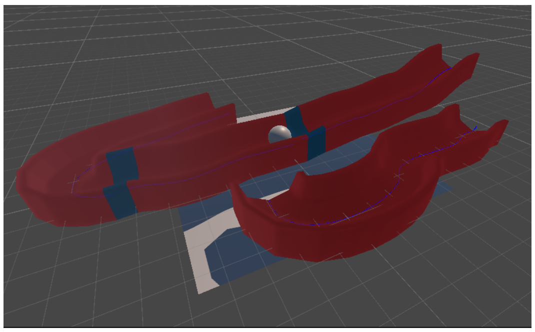
To make the drawing process more intuitive and pleasant, the temporary path drawn up to any point in time while pressing the bumper is shown to the user in form of a dotted trace. To edit the existing tracks, the user can be erase them by touching them with the controller in erase mode, which is activated when the trigger and bumper buttons are both pressed on the controller.

3.2. Object store

The object store panel features multiple buttons, enabling users to spawn a variety of special building blocks. These include marbles, wide-to-narrow track blocks, funnels, seesaws, and a bowl that features sparkly animations when the marble lands inside. These components are derived from pre-made assets [12]. The store is shown in Fig. 3.



(a) The splines created for the track generation.



(b) The resulting track mesh.

Figure 2. Track generation process demonstrating a 4-segment design. (a) Illustrates the splines used to define the track path. (b) Shows the resulting 3D mesh created based on these splines. This process highlights the translation from user-drawn paths to the final track geometry.

Objects can be spawned by pointing towards their respective images and pressing the trigger button on the Magic Leap Controller. Once spawned, objects can be moved and rotated by pointing at them and pressing and holding the trigger. Initially, marbles spawn in a floating state, and gravity is applied once the user releases the trigger. To facilitate easier retrieval of fallen marbles, they are automatically pulled in front of the controller when the user attempts to grab them.

4. User Study

The questions for the 4.2 and 4.3 sections are all taken from the USE questionnaire presented in the paper by Arnold M. Lund [5]. In the USE questionnaire, there are three sections: Usefulness, Satisfaction, and Ease of Use. Since this application is a game, we are not particularly interested in the "Usefulness" section, which is why it was omitted from this user study. The questions are based on a 1-7 Likert scale, where a higher score indicates stronger agreement with the statement. This user study was conducted in three main stages. First, participants were introduced to the commands and buttons of the application through a brief tutorial. Following this, they were given the opportunity to use the application freely, without being assigned any specific tasks to complete. Finally, after they finished using the application, participants were asked to fill out a questionnaire to evaluate the system based on their experience.

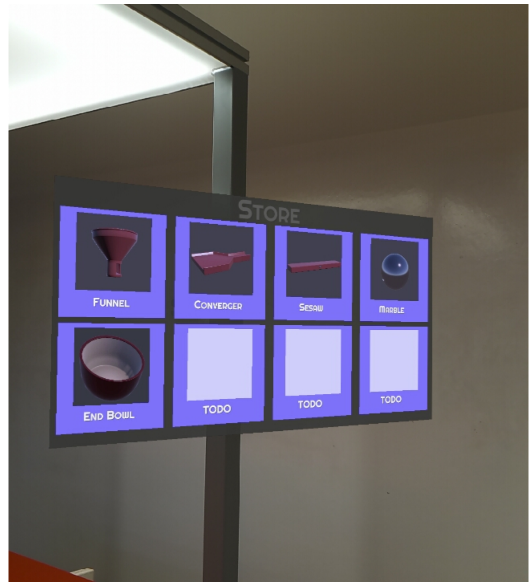


Figure 3. The store floats around the user and allows the addition of special blocks for a more sophisticated track. Clicking on each panel spawns the corresponding item, which can then be grabbed and used.

4.1. Demographics

The study involved 11 participants, with a mean age of approximately 24.3 years, ranging from 19 to 28. The participants were mainly men, with a ratio of 90.9% men and 9.1% women. In terms of AR experience, the participants had varying levels of expertise, with the following distribution:

- no experience: 27.3%.
- 1-10 hours of experience: 27.3%.
- 11-50 hours of experience: 36.4%.
- over 100 hours of experience: 9.1%.

4.2. Satisfaction

This section evaluates the level of satisfaction users had with the system. Participants were asked to rate a series of questions about the overall satisfaction, perceived usefulness, and enjoyment of the system. The mean and standard deviation values for the satisfaction section are presented in Table 1.

Notably, questions such as "I would recommend it to a friend" (mean = 6.36) and "It is fun to use" (mean = 6.55) received particularly high ratings, reflecting strong satisfaction and enjoyment. On the contrary, participants were less satisfied with statements like "I feel I need to have it" (mean = 5.36), which scored lower.

Table 1. Mean and Standard Deviation for Satisfaction

Question	Mean	Std
I am satisfied with it.	6.18	0.87
I would recommend it to a friend.	6.36	0.80
It is fun to use.	6.54	0.68
It works the way I want it to work.	5.63	1.50
It is wonderful.	6.36	0.80
I feel I need to have it.	5.36	1.68
It is pleasant to use.	6.00	1.18
It is easy to use.	6.27	1.00
It is simple to use.	6.45	1.03
It is user friendly.	6.27	1.10

The overall results indicate that participants were largely satisfied with the system, with most items scoring above 6 on the 7-point scale and a mean score of 6.14. The standard deviation of 0.74 between users suggests that while there was a general agreement on the system's satisfaction, there were some variations in how participants perceived its usefulness and enjoyment, likely reflecting differences in personal preferences or prior experiences with similar systems.

4.3. Ease of Use

This section evaluates how users perceive the ease of use of the application. The ease of use is assessed by several questions that focus on the participants' ability to interact with the system without significant difficulties, the flexibility of the system, and how intuitively the system can be used. The mean and standard deviation values for the ease of use section are presented in Table 2.

Table 2. Mean and Standard Deviation for Ease of Use

Question	Mean	Std
It requires the fewest steps possible to accomplish what I want to do with it.	6.63	0.50
It is flexible.	5.81	1.32
Using it is effortless.	5.90	1.37
I can use it without written instructions.	5.63	1.74
I don't notice any inconsistencies as I use it.	5.63	1.62
Both occasional and regular users would like it.	6.09	1.04
I can recover from mistakes quickly and easily.	6.09	1.22
I can use it successfully every time.	6.09	1.22

In particular, participants found that the system required "fewest steps to complete tasks," with a mean score of 6.63 and a relatively low standard deviation of 0.50, indicating general agreement among participants. The two lowest rated items were "I can use it without written instructions" and "I don't notice any inconsistencies as I use it," both scoring 5.63, with the highest standard deviations of 1.74 and 1.62, respectively. This suggests that some users found these aspects more challenging than others.
Participants rated the system as quite easy to use, with an average mean score of 5.98. The standard deviation of 1.07 between users indicates a high variation in ease of use perceptions, likely due to differing levels of AR experience.

5. Discussion and Future Work

The development of *mARble-run* highlights the exciting potential of AR to merge interactive gaming with real-world environments. By enabling users to design custom tracks in their surroundings and simulate realistic marble physics, the game succeeds in creating an engaging and immersive experience. The strong user satisfaction scores in our study validate the game's intuitive design and entertainment value. However, there are still areas for improvement and opportunities for expansion that could further enhance its impact and appeal.

5.1. Usability and User Experience

One of the key strengths of *mARble-run* lies in its intuitive interface and ease of use, as evidenced by high satisfaction ratings in the user study. The Magic Leap Controller allows for precise and reliable interaction, enabling players to quickly create and modify tracks. However, some participants expressed a desire for additional guidance during the initial stages of gameplay. Incorporating an interactive tutorial or context-sensitive tips could further enhance accessibility, particularly for users with limited AR experience. Such a feature could guide new users step-by-step through track creation, object placement, and marble interactions. For example, a tutorial might start with placing a simple straight track and gradually introduce curves, loops, and special effects, ensuring users understand the tools that are available to them.

Participants also noted that the game's simplicity made it enjoyable, but some expressed interest in more advanced features to sustain long-term engagement. Expanding the range of tools and options available during track creation, such as special effects or unique track elements like accelerators or moving platforms, could make the experience more dynamic and customizable while maintaining its approachable design.

5.2. Limitations and Possible Enhancements

While the game excels in providing an accessible and entertaining experience, several areas require attention to enhance functionality and user satisfaction further. One critical issue is the creation of paths outside the user's field of view, which can make it challenging to maintain track continuity. Implementing a gap-filling algorithm could address the challenge of creating paths outside the user's field of view. This algorithm would automatically detect and fill gaps in the track by interpolating between the end points of incomplete segments. Such a feature would ensure smooth and continuous track designs, reducing the likelihood of disruptions or inconsistencies while maintaining an intuitive user experience.

Another enhancement would involve improving the precision and flexibility of the track creation process. By allowing users to create intricate designs, such as loops or complex pathways, without compromising track quality, the game could significantly expand its creative potential. Advanced tools like grid snapping, adjustable curvature settings, and a preview mode for path adjustments would make the drawing experience more intuitive and precise.

5.3. Educational Potential

mARble-run's simplicity and realistic physics simulations position it as a valuable tool for educational applications. By engaging users in hands-on track creation and observing real-time physics, the game can effectively teach concepts such as gravity, friction, and momentum. Incorporating guided learning modes, such as challenges that demonstrate specific physics principles or quizzes integrated into gameplay, could expand its utility in educational settings.

5.4. Future Directions

To address the current limitations and unlock new possibilities, we propose the following areas for future work:

1. **Multiplayer Functionality**: Introducing multiplayer modes would enable collaborative track design and cooperative gameplay. Players could build tracks together, race marbles, or challenge each other with custom-designed puzzles. Implementing cross-platform multiplayer features could further enhance accessibility and reach.
2. **Enhanced Gameplay Mechanics**: Adding features such as adjustable marble properties (e.g., size, weight, or material) and dynamic environmental interactions (e.g., obstacles, ramps, or accelerators) would increase depth and replayability. Players could experiment with different configurations, fostering creativity and problem-solving skills.
3. **Improved Usability**: Building on the game's intuitive interface, future iterations could introduce more responsive feedback mechanisms, such as visual or haptic cues during track creation. Additionally, refining the menu system to streamline access to features would enhance the overall user experience.
4. **Expanded Educational Features**: Developing a dedicated educational mode could make mARble-run a valuable tool in classroom settings. For example, educators could use the game to demonstrate physics principles such as gravity, friction, and momentum by setting up pre-designed challenges where students must predict how marbles will behave under specific conditions. A "sandbox mode" could allow students to experiment freely with these principles, reinforcing learning through hands-on interaction. Additionally, incorporating quizzes or prompts during gameplay to explain key concepts in real-time could further enhance its educational value.
5. **Broader Hardware Support**: While the Magic Leap 2 offers advanced AR capabilities, supporting other AR platforms such as Microsoft HoloLens or mobile-based AR systems (e.g., ARKit and ARCore[2]) would expand the game's accessibility and market reach.
6. **User-Created Content**: Allowing players to share their custom tracks and challenges with the community could foster a collaborative ecosystem and enhance the game's longevity. A track editor mode or an online repository for user-generated content would encourage creativity and engagement.

6. Conclusion

mARble-run highlights how AR can effectively combine entertainment and education, offering a fun and engaging way to explore concepts like physics and problem-solving. While the initial version had a lot of positive reviews, there is still plenty of room for growth and improvement. Expanding the range of features, such as more customizable tracks, interactive challenges, or collaborative multiplayer modes, could significantly enhance its appeal. Improving accessibility, for instance by supporting a wider variety of devices or providing features for users with disabilities, would make it more inclusive.

By focusing on these areas, *mARble-run* has the potential to grow into a well-rounded platform that serves both entertainment and educational purposes, appealing to a wide audience in a meaningful way.

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