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Original Paper

Developing a baseball cage in Virtual Reality environment highlighting the associated physical calculations

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Abstract

In recent years, the evolution of virtual reality (VR) technology has transformed the way humans interact with computers, including in the education sector. Its ability to create immersive and adaptive environments is being utilized to enhance the learning experience. In this study, a baseball cage was simulated to help students learn physics concepts. This VR baseball cage uses the fundamental principles of sports physics to quantify user performance in real time using metrics such as speed, launch angle, and impact force. Unlike traditional teaching methods, this proposal uses a multimodal interface and visual programming with Blueprints to capture kinematic data and provide feedback via a virtual laboratory. The simulation results demonstrate the technical synchronization between the virtual bat and ball, aiming to validate the physical theory of speed, angle and force in a virtual environment and sense the changes each time the end user hits a ball. The system achieves a data processing accuracy of over 99%.

Keywords: immersive learning, baseball physics, visual programming, virtual reality, telepresence

1. Introduction

The evolution of virtual reality (VR) has transformed human-computer interaction. Pioneers like Jaron Lanier coined the concept in the 1980s, and it has since developed into a sophisticated modelling technology, as discussed in Lanier (1992). This research project aims to present a VR application designed for educational purposes. It enables users to visualise and correct their baseball technique in real time by considering the relevant variables. Regarding related work, the literature establishes that VR immerses users in three-dimensional sensory environments through devices that translate physical actions into digital signals. According to Quinga-Villa (2024) and Ordoñez (2020) a fundamental concept is "telepresence", which is described as the illusion of 'being in a place or environment, even when one is physically in another'. In order to achieve a high degree of immersion and isolate the user from the physical world, modern systems such as the Meta Quest 2 require certain key features, including real-time interaction, a high frame rate (FPS), sharp resolution and precise stereoscopic vision, which tricks the perception of the human eye.

The value of this technology in education currently lies in its ability to facilitate evidence-based learning through data analytics, as discussed in Lara (2022), Loureiro (2019), Yépez (2020) and Whitelock (2000). Unlike conventional simulators, modern development engines can translate complex physical movements into quantifiable performance metrics such as speed, angle and impact force. This motivates the implementation of this tool as an innovative alternative to traditional sports teaching, as demonstrated in Acheson (2026), Chen (2025), Wilkins (2025), Chung (2025) and Calderón (2019). Learning and participation in these environments is effective when there is multimodal interaction, where sounds, images, and tactile sensations are exchanged simultaneously.

The model selected to represent the ball's trajectory was set as follows setting a parabolic movement, as shown in Figure 1. The mathematical model used follows from equation (1).

$$\vec{F}_g+\vec{F}_d+\vec{F}_m=m\vec{a} \quad (1)$$

Where m is the mass of the ball, a is the translational acceleration, F_g is the gravity force, F_d is the drag force and F_m is the Magnus force.

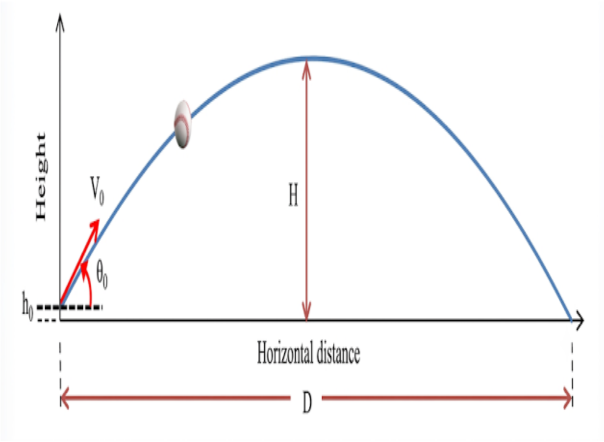

Figure 1. Ball trajectory (Source: López Sánchez, 2023).

All details about gravity, drag and Magnus forces are described in López Sánchez (2023).

2. Methodology

2.1 System architecture and Virtual Reality hardware

The Meta Quest 2 hardware was used to create the immersive environment. Effective implementation of this device requires a packaging and distribution method managed by professional tools such as the Meta Quest Developer platform, which allows technical performance to be monitored and ensures that the simulation maintains an adequate frame rate. The hardware works in conjunction with an interface that converts physical actions into processable signals and provides natural sensory feedback, as shown in Figure 2.

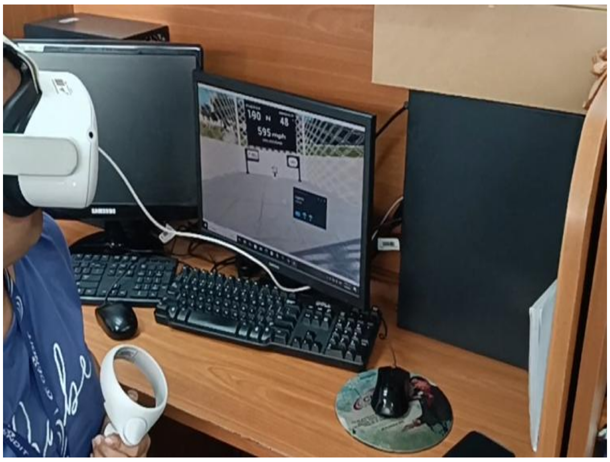

Figure 2. Baseball cage simulation.

2.2 Design Logic and Technical Development

The development was carried out using the Unreal Engine design platform, with visual programming methods employing Blueprints applied to quantify the user's kinematic performance in real time. As shown in Figures 3 and 4 specific nodes in the bat actor (BP_Bat) capture fundamental physical information adjusting the code following equation (1). The system then processes this raw data using integrated mathematical operations to transform it into standardized metrics such as miles per hour (MPH) and the distance in feet (ft). This internal logic is linked to the visual components of the environment using reference variables (such as TVvarsBat), enabling fluid data communication.

To integrate the projectile into this analytical ecosystem, the ball was configured as an independent actor (BP_Ball), as shown in Figures 3 and 4. This actor simultaneously acts as a receiver of physical force and an emitter of information. Its behaviour is governed by the system's collision engine and metrics are activated the instant geometric overlap with the bat is detected, via precise events such as Event ActorBeginOverlap. This immediately triggers a chain of vector calculations to determine the exit trajectory and speed, ensuring the digital response strictly reflects the mechanical energy applied by the user.

2.3 Physical Metrics and Teaching Use

This technical design is based on the scientific principles that the speed at which the ball is hit after making contact with the bat greatly influences the distance traveled, it is the fundamental parameter for achieving great hits. Based on this premise, the virtual environment transcends mere recreation to function as a laboratory for didactic and numerical experimentation.

To consolidate the learning process, information calculated after impact is instantly sent to the main visual interface, which is represented by a virtual television (BP_TV). The system logic uses Set Text nodes to dynamically modify screen components as shown in Figures 3 and 4, through the execution of bridge functions or custom events — specifically Actvel, ActForce and ActAngle. This mechanism ensures that the user observes real, instantly calculated results, translating the collision into an immediate technical diagnosis of force, angle and initial speed rather than displaying static or predetermined figures.

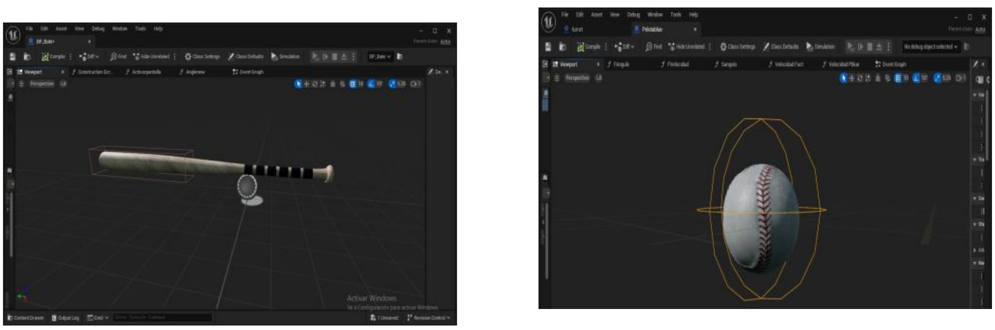

Figure 3. Blueprints for the bat and the ball.

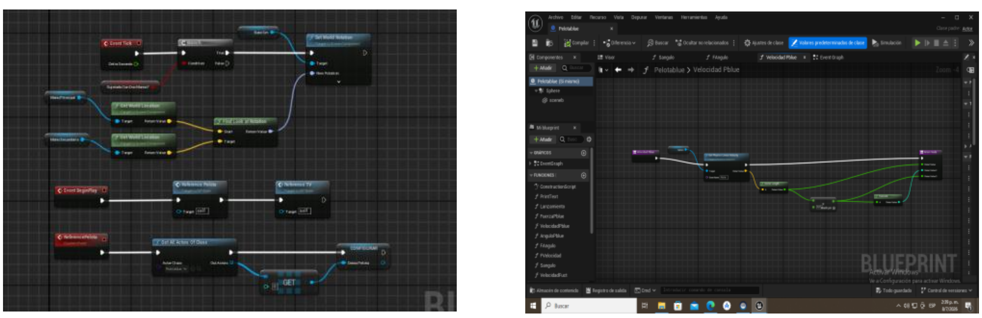

Figure 4. Programming the bat and the ball.

3. Result

Before playing in the VR environment, the physical model was validated using results obtained in Unreal Engine. Game data from the fifth inning of Game 5 of the 2016 NLCS was used, specifically a fly ball hit to center field by Kris Bryant, as reported by Nathan (2016). The accuracy was over 99.60%, obtained through simulated data and the Mean Absolute Percentage Error (MAPE) calculation, when comparing the model with Unreal Engine as shown in figure 5.

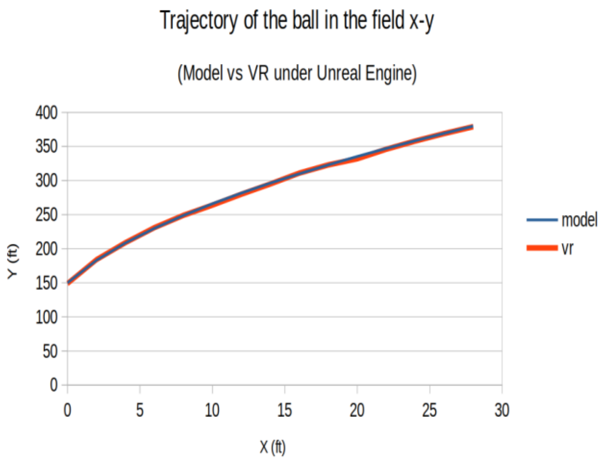

Figure 5. Physical model vs VR under Unreal Engine.

Figure 6 shows the physical model validated using the results from the model detailed in Section 2.1 by López Sánchez (2023), compared with Unreal blueprints. In this case, the height of the ball after hitting it versus the horizontal distance is considered.

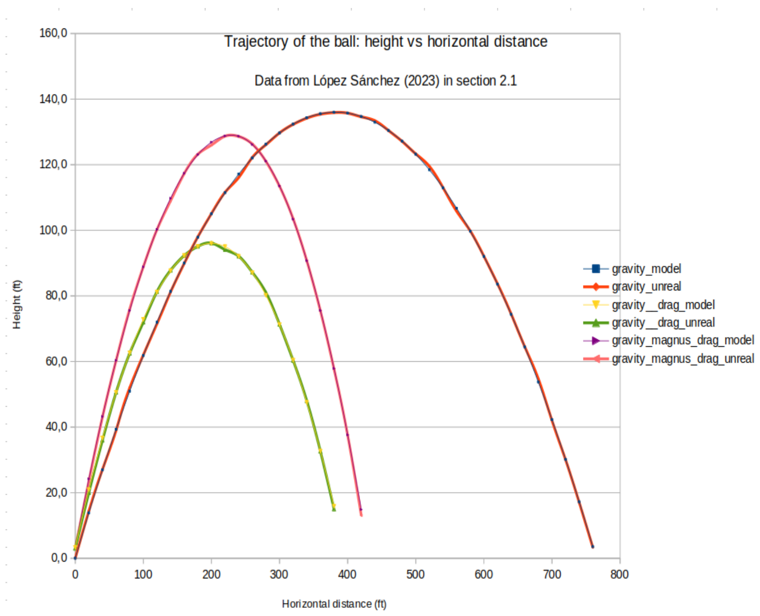

Figure 6. Trajectory of the ball: height vs horizontal distance according with example in section 2.1 by López Sánchez (2023) considering only gravity, gravity+drag and all the forces.

Using MAPE, the accuracy of the model compared to the Unreal engine was found to be 99.31% (for gravity only), 99.12% (for gravity and drag) and 99.01% (for all forces) based on the simulated data.

The development process culminated in the creation of a functional simulated environment that accurately captures kinematic metrics. Figure 7 shows the simulation of the baseball environment, confirming the architecture's technical capability to process force, angle, and speed parameters in real time. The data flow between the collision engine and the programming logic proved to operate synchronously. Upon impact between BP_Bat and BP_Ball, the system instantly sends information via bridge functions to the screen display (BP_TV), visually reflecting the projectile's initial speed. This dynamic visualization isolates the physical components of batting and allows them to be analyzed separately within the computer-generated environment.

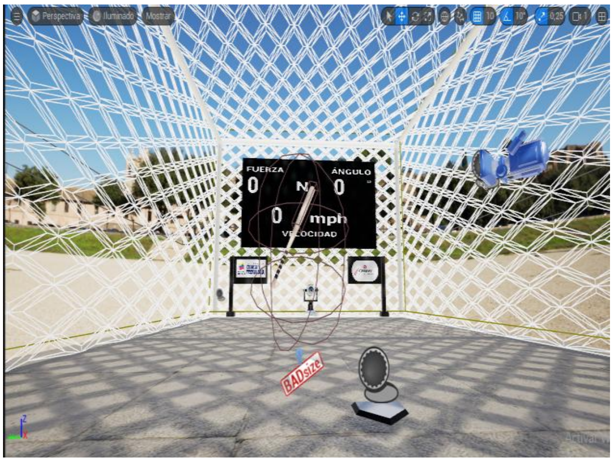

Figure 7. Virtual Reality Game Space Simulation

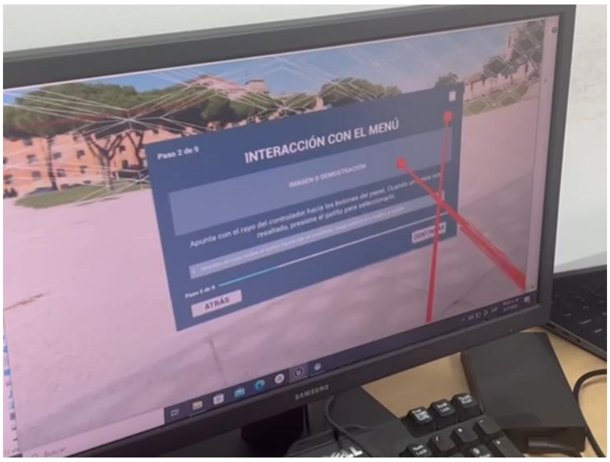

Figure 8. Starting tutorial.

4. Discussion

This technological architecture has an educational purpose thanks to its ability to use physical variables in a real baseball environment and provide instant visual feedback on the monitor. By observing how energy transfer and movement affect the on-screen values, athletes can internalise the mathematical relationship between launch angle, speed and distance travelled, as well as complex physical concepts that affect the flight of the ball, such as gravity and air resistance. This allows the user to adjust their stance and swing power consciously, based on empirical data, transforming traditional training into a comprehensive process in which psychomotor skills are developed alongside a practical understanding of the physics of sports explained through starting tutorial for end users (Figure 8).

5. Conclusion

The system transforms complex physical actions into quantifiable sports performance metrics (MPH, degrees, force) using visual programming and VR tools reaching an accuracy indicated in section 3.

The technical architecture allows the environment to function as an experimentation laboratory, where ball initial speed is validated as the fundamental parameter for analyzing batting success.

Synchronization between the bat and the ball ensures visual responses in the interface, providing a technological basis for data feedback that surpasses traditional teaching methods. In this case, Continuous Collision Detection was employed in Unreal Engine to prevent the ball from passing through the bat between two consecutive frames when traveling at high speed, while a time step of less than 0.01 was used to achieve greater precision in applying expression (1).

The system's instant response theoretically validates the use of Unreal Engine as a scientific experimentation laboratory, supporting some postulates of baseball physics.

Acknowledgements

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