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Dynamic Physics Educational Application for AR Environment

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Abstract. We propose a physics simulation application designed for Augmented Reality (AR), aiming to help high school students understand physical concepts such as mass, gravity, and friction. This application incorporates real-time object movement on a ramp, vector modulation based on forces, and physics calculations using user-specified parameters. Users can observe how objects respond to physical laws expressed by relevant formulas, enhancing comprehension of fundamental principles. Our research aims to enhance physics education by delivering an immersive learning experience through mobile devices. Through this approach, we also seek to make physics more accessible for students, fostering a grasp of challenging concepts.

Keywords

Augmented Reality, Unity, physics, educational application

1 Introduction

High school students often encounter difficulty in understanding physical phenomena when they begin learning physics. Consequently, they find themselves unsure about the application of formulas or trigonometric functions. Having tutored high schoolers in physics, the author recognized that their struggle arose at least partly from a lack of visual representations and dynamic movements when studying from textbooks. This realization led the author to en- vision creating dynamic physics simulations within Augmented Reality (AR) environments for enhanced visualization. The objective of this research is primarily to provide practical assistance to students who face challenges in comprehending physics concepts, as well as to people who have a curiosity about physics. Additionally, it aims to benefit students who are unable to attend cram schools due to financial constraints, thereby improving the quality of independent study.

2 Related Work

The work of Kaufmann and Meyer [**2008**] describes an augmented reality application designed for physical mechanics education using a head-mounted display and wireless pen.

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It employs a physics engine originally developed for PC gaming to simulate real-time physical experiments in mechanics. This allows students to conduct experiments in a three-dimensional virtual world. The application provides tools for analyzing forces, mass, paths, and other object properties.

The system developed by Sung et al. [**2019**] employs a video see-through AR setup with Microsoft's Kinect V2 depth sensing for environment recognition and a real-time soft body simulator utilizing GPU parallel processing. It features a simulator of the physical deformation and movement of 3D volumetric objects. The soft body simulation enhances realism compared to the rigid body, making it effective for physics education. A survey with 10 physics education students revealed 93% interest in using the system for education.

Web-served applications by PhET offer physics simulations such as force and motion, incorporating high school or university-level physical phenomena.

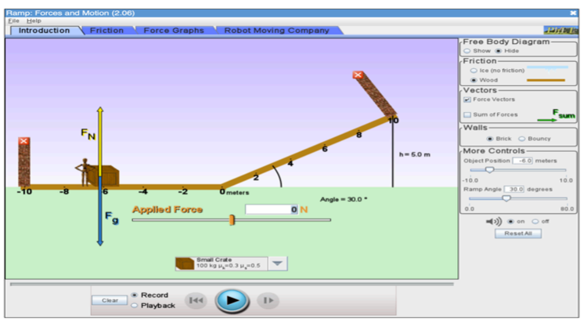


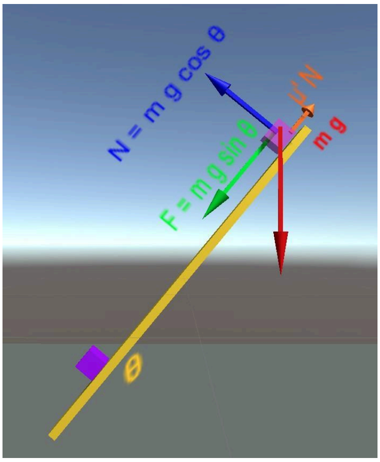
Figure 1: Web-based PhET "Force and Motion" simulation

3 Methods

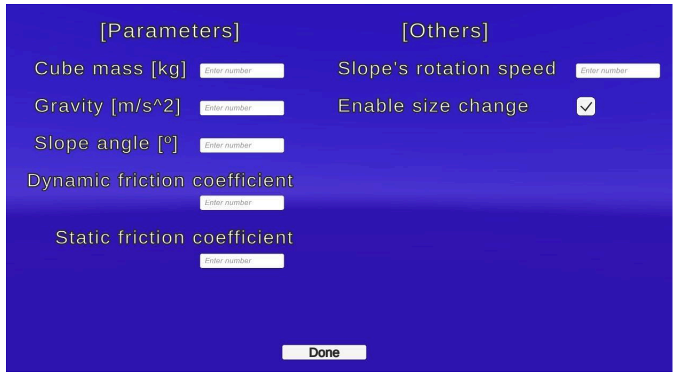
3.1 Application of Unity Engine

Unity's built-in physics engine is used to simulate the movement of a cube on a slope ramp. This allows the application of static and dynamic friction coefficients to a cube by accessing to collider component as well as slope physics material, which static friction, dynamic friction, and bounciness can be adjusted. When an object slides down a ramp, it is subject to the force perpendicular to the incline, gravitational force, normal force, and friction based on user-specified parameters such as mass, angle of slope, gravity, and friction coefficients. Values of static and dynamic friction coefficients affect the movement of the free body diagram, slowing down its speed (when an object on a slope is moving, gravitational force according to the slope exceeds that of friction) or stops on a slope until it reaches maximum static friction force (when a cube on a slope is static, the force of the cube according to the slope is exactly opposed by friction).

Figure 1 illustrates that while a cube is descending, another cube remains on the slope so that a user can see what sort of forces act upon a body. Each vector modulates its length extending or contracting according to the combined forces. From the settings pane in Figure **2a**, a user can input parameters for mass, dynamic friction coefficient, and static friction coefficient (static friction coefficient must be greater than the dynamic friction co-coefficient. Thus, a wrong parameter causes an error message). In addition, a user can set a slope angle (from horizontal, 0° up to vertical, 90°), and gravity.



(a) Game view in Unity



(b) Settings pane

Figure 2: As the ramp of the slope steepens, the vector modulates according to the user-specified parameters.

Optional settings include the ability to modify the speed of the steepening slope of the ramp until reaching the set angle. Users can also enable the alteration of the size of a cube based on its mass.

3.2 Formula

The following formulas are used for mass and gravity simulation shown in Figures **2a and 2b**: The gravitational force according to a slope is given by

$$F = mg \sin \theta.$$

Normal or kinetic force of an object is given by

$$N = mg \cos \theta.$$

Dynamic friction force of an object is given by

$$F' = \mu' N.$$

Static friction force of an object is given by

$$F = \mu N.$$

F and F' are forces (parallel to the surface) on a free body [N = kg m/s^2], N is the normal force (perpendicular to the ramp) [N = kg m/s^2], m is mass [kg], and g [m/s^2] is the gravitational constant of acceleration, θ [°] is the angle of the slope, μ is the scalar (dimensionless) static friction coefficient, and μ' is the scalar (dimensionless) dynamic friction coefficient ($\mu' < \mu$).

3.3 Unity AR Foundation Architecture

Unity AR Foundation was used to apply a Unity AR scene to a mobile device. AR Foundation helps developers build cross-platform AR applications using Unity as shown in Figure 3. Within an AR Foundation project, AR features are activated by incorporating manager components into the Unity scene. Such an abstracted project is applicable for iOS and Android devices once the build setting in Unity has switched. Upon completion of a build within the Unity editor, an Xcode project file is generated (only in the case of iOS). Subsequently, the project can be installed by connecting to a designated device, facilitating the deployment of the AR project onto the targeted device. Following deployment, the project on the device remains accessible for a certain duration without necessitating continuous connection to a computer, allowing autonomous functionality.

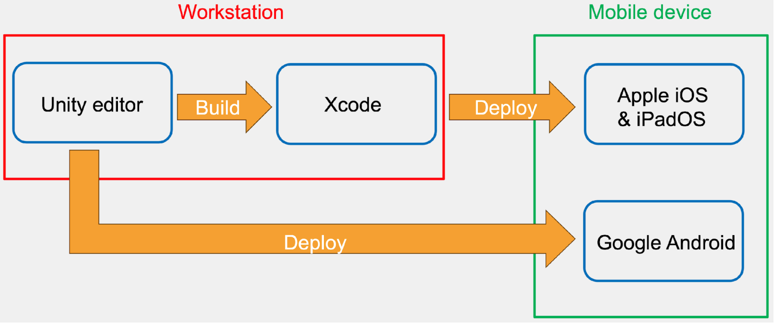


Figure 3: Unity deployment to mobile device

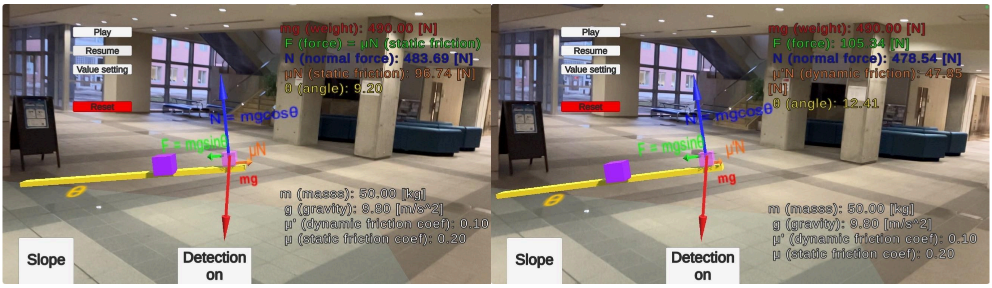
3.4 Implementation of Mobile Device

When the project is opened on a phone, a user can detect the floor or horizontal surface such as a tabletop, and place a slope with the buttons. From the "Value Setting" (Figure **3**), each user-specified parameter can be changed at any time. During the simulation, a user can pause (by clicking the "Pause" button) and resume (by clicking the "Resume" button) the simulation to see certain values at an angle. Also, the real-time value shift can be seen at the right top of the screen. When the "Reset" button is clicked, placed objects are restored, and user-specified parameters persist.

Figure **1** shows the phenomena of force according to a slope ($F = mg \sin \theta$) and static friction (μN) balancing, while Figure **2** represents that force according to a slope is greater than dynamic friction ($\mu' N$), as realized by Unity's built-in physics simulator.

3.5 Survey

We surveyed eight randomly selected subjects within the age range of 16–47 years (average 28.9), half males. Three of them were university students, two of them were high school students, and the others were working adults. Regarding background, all of the working adults reported either "I didn't learn physics at school" or "I don't remember having learned physics at school." For the students who answered, "I learned physics at school" we further inquired which parts of physics they found to be less understandable. After the survey, the eight subjects tried our application. Then, they evaluated the experience through a survey administered via Google Forms.



(a) Cube subject to static friction (b) Descending cube subject to dynamic friction

Figure 4: See-through AR

Table 1: With a maximum of three selections allowed, the five subjects who learned physics in high school selected difficulties in physics. One of them answered, "Didn't face any difficulties."

Selections	Number of Replies
Understanding formulas	2
Understanding the movements of objects	3
Judging which formula to apply	1
Using high school-level calculations (trigonometric functions)	2
Didn't face any difficulties	1

Table 2: Summary of the post-experience survey. Non-parenthesized numbers show the number of to-replies, and the parenthesized number shows the number of subjects who learned physics in high school.

Questions	Yes	No	Neither
Do you think this application will help you understand physical phenomena	8 (5)	0	0
Was the screen easy to see?	5 (3)	2 (1)	1 (1)
Was the application easy to use?	7 (5)	1	0
Would you like to use this application when studying physics?	7 (4)	0	1 (1)

4 Results

The AR simulation realizes physical phenomena in an interactive environment. Users can set parameters for angle and mass, enabling them to observe how each force changes through real-time calculation. This dynamic effect enhanced understanding for subjects who reported difficulties comprehending phenomena from ordinary textbooks (Tables **1** and **2**). While we received positive feedback from users regarding the enhancement of the physics study, there were negative responses regarding the simplicity of the user interface (Table 2). The two subjects suggested integrating sliders for parameter input and making force transitions visible through graphical representations. Consequently, we aim to improve the visual design and quality of the interface.

5 Discussion

This research demonstrates that both student and non-student subjects acknowledged the effectiveness of the application – a scope not addressed by previous studies, which did not include these cohorts as their target subjects. In terms of accessibility, achieving stand-alone AR simulation requires mobile devices such as contemporary smartphones or tablets in our research. Consequently, an increase in the utilization of AR physics simulators on mobile phones within high school education is expected, as it eliminates the need for wireless pens, controllers, or head-mounted devices. This availability is particularly beneficial for students who lack access to such exotic or expensive devices.

6 Future work

Based on feedback received from the subjects, we intend to implement a slider for parameter input and utilize graphs to visualize force transitions. Additionally, we aim to expand the simulation by integrating velocity and acceleration dynamics associated with the descent of a cube on a slope, along with the ability to place a cube on a slope through drag and drop functionality.

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