Computation and visualization of physics equations

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Abstract

This paper describes the creation and formative evaluation of the Virtual Lab (VLab), a virtual environment for investigating the kinematics and dynamics of two-dimensional motion. We aimed to compute and simulate physics equations in the computer environment. For the application phase, we limited the physics equations to two-dimensional motion. The second step after modeling the equations with the computer is aimed to visualize and simulate them. And care has been taken to ensure that these simulations are interactive. The ability to change values such as angle, mass, vector sizes, the position is added in line with this care. On the other hand, the main purpose of this study is to model not only these motions but also neglected factors in experimental environments to obtain more realistic observations and results. Accordingly, the equations were implemented in the computer environment not only for insulated environment equations but also for uninsulated environment equations such as air friction.

Keywords: computational physics, simulation, physics engine, virtual laboratory.

INTRODUCTION

This study aimed to help by creating a virtual laboratory for those who want to examine the projectile motion of mechanical physics. In this way, less costly virtual laboratory simulations were created instead of creating real-life laboratory environments.

For a very long time, there are people who have created works outside the reality they have lived. It can be said that the sum of the assets existing relative to a reference point is the reality of that reference point. There are many ways to realize this desire such as role-playing games, simulations, etc.

A simulation is the imitation of the operation of a real-world process, a system, or a dream world (Banks et al., 2010). Simulations are used to show the possible effects of situations before real-time events. They are used in many contexts, such as engineering, testing, training, education, and video games, etc. In this study, computer simulations are emphasized on the physics science.

Nowadays, due to the advancement of computer graphics and hardware parts, some simulations can be easily created virtually. Especially, the increase in computer games has inspired the works in this area. Experimental environments or direct implementations of many operations, which are difficult to perform in real life, using computers can be created.

Computer simulations are called in many areas as "sim". Since computers give close results during the estimation phase, it helps us to avoid examining extreme and off-topic situations. With the help of the dynamic structure of computer-based designs, the situation to be examined can be diversified for each different case.

Computer simulations are used in a wide range from economy to education, from the military to the entertainment sector. In 2006, M. Fontana suggested a systematization of the relationship between simulations, mathematics, and economics (Fontana, 2006). In 2016, Malgorzata conducted an experimental study on the effect of computer simulations on economic analysis (Łatuszyńska, 2016). In 2019, Gaffeo et al. offered a computer simulation-supported proposal to take measures regarding bank debt in times of crisis (Gaffeo et al., 2019). In 2019, Balaban used a computer simulation to improve the design of military vehicles performing a computer-based crash simulation (Balaban, 2019). Again in 2019, Fox et al. designed a simulation for modeling military decision-making (Fox and Burks, 2019). In 2019, Bertacchini et al. proposed a didactic computer simulation to cover many areas of mathematics (Bertacchini et al., 2019).

The science of physics deals with matters, energies, and their relationships with each other. Physics has six major areas that are mechanics, thermodynamics, optics, waves, electromagnetism, and modern physics (Young and Freedman, 2012). The main concern of this study is the projectile motion of mechanical physics.

The mechanical physical phenomenon is described quantitatively in three fundamental quantities: time, length, and mass. Each object has a mass. Each object or action has physical dimensions. Each movement is completed in a certain time. This can be summarized by saying that each object travels a certain distance at a certain time during a movement. Mass is measured with the kilogram, the length is measured with the meter, and time is measured with second in the metric system. However, some countries have own measurement system.

It is understood that the basic subjects of mechanics are subjects such as motion, work, energy, collision, rotation, flexion, and gravity. Thus, experimental environments should be designed to perform and observe at least collision, flexibility, fall, etc. tests. On the other hand, the setup costs of this type of laboratory are very high. With the help of this study, these expenses can be reduced.

In 2001, Jimoyiannis and Komis developed computer simulations in physics teaching and learning (Jimoyiannis and Komis, 2001). In 2019, Park developed a simulation-based formative assessment model and modeled two topics: motion in two-dimension and conversation of energy (Park, 2019). In 2020, Sankaran et al. developed a physics-driven blood-flow simulation (Sankaran et al., 2020).

In this paper, there are 5 chapters. The methods which are used are described in Chapter 2. How these methods are modeled is explained in Chapter 3. In Section 4, inferences are revealed and future works are discussed.

METHOD

In this study, a virtual projectile motion laboratory is designed. In the mechanical physics field, almost all equations are examined isolated from the real environment. Many factors are difficult to follow in the true nature of the movement. Therefore, these difficult to calculate factors are ignored and the approximate results are processed.

Another purpose of this study is to examine the neglected factors. At this point, the question "What are the neglected factors?" should be sought. The main neglected factors are air friction, gravitational acceleration, and shape of the object. Because of the earth's atmosphere, objects move in the air on the earth, not in the void. If there is no air friction all objects are fall at the same time from the higher places regardless of their shape and mass. As in the best-known example, an iron rose and a feather falls to the ground at the same time in an airless environment (Cox, 2014).

Projectile motion is the motion of an object thrown or projected into the air, subject to only the acceleration of gravity as in Figure 1.

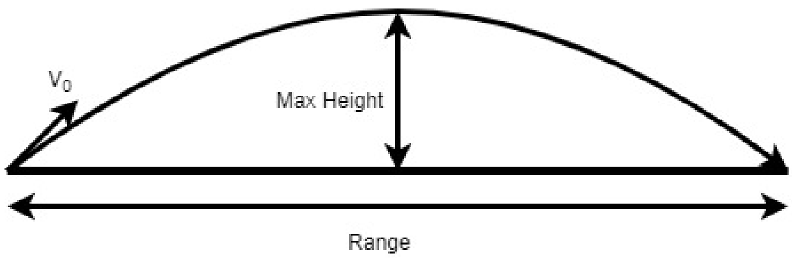

Figure 8. An example of projectile motion

This motion gets the information of the V0 initial velocity and the initial angle (Θ). If air friction is included in the system, some other parameters that are air density (ρ), the mass of the object (m), the dimensional constant (C), and the cross-sectional area of the projectile (A) are needed to calculate air friction force (F_d) as in Equation (1). Equation (3) and Equation (4) show that F_d's the X-axis and Y-axis values respectively. In Equation (2), D is the drag coefficient. The weight of the mass (W) is calculated with multiply g and m such as $W = gm$. The negation in Equation (3) says that air friction force slows the object. Also, the negation in Equation (4) shows that projectile drops.

$$F_d = DV^2 \tag{1}$$

$$D = \frac{\rho C A}{2} \tag{2}$$

$$F_{dx} = -F_d \cos \Theta \tag{3}$$

$$F_{dy} = -W - F_d \sin \Theta \tag{4}$$

Physics is all about rates of change. During the motion, the air friction affects the projectile every the smallest time interval. To examine all of these changes, Euler's numerical method is used. Euler's method is a simple way to approximate the solution of ordinary differential equations numerically. Assuming the Equation (5), the solution is $y = f(x)$.

$$\frac{dy}{dx} = f'(x) \tag{5}$$

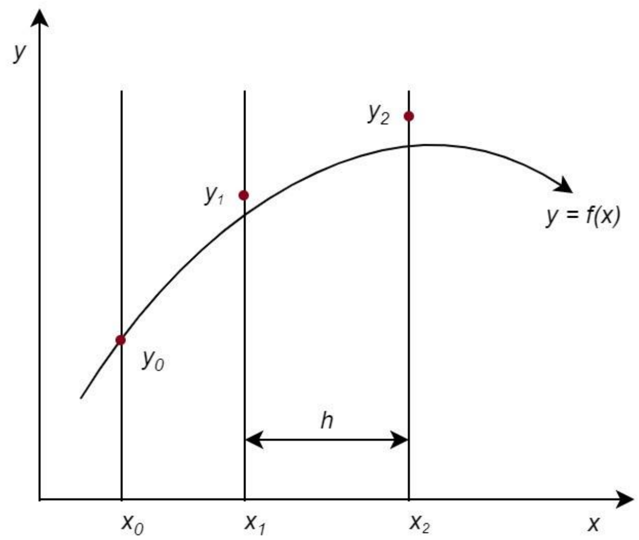

Figure 2. Representation of Euler's numerical method

If we combine the information in Figure 2 with this Equation (5), we can say that Euler's method is numerically examining each Δx interval which means x_{i+1}-x_i from a known starting point (x_0, y_0) as in Equation (6). Thus, the solution is $\Delta y = f'(x)\Delta x$.

$$\frac{dy}{dx} \cong \frac{\Delta y}{\Delta x} \tag{6}$$

If we expand this equation system, we get an equation system as in Equation (7). As known, the acceleration (a) is the derivation of the velocity (V) and time (t) and the velocity is the derivation of the range (x) and time. Therefore, the system of equations in Equation (8) is obtained. Here, Δt represents the smallest possible time interval.

$$x_n = x_{n-1} + \Delta x$$
$$y_n = y_{n-1} + f'(x_{n-1})\Delta x \quad (7)$$

$$t_n = t_{n-1} + \Delta t$$
$$x_n = x_{n-1} + v_{n-1}\Delta t$$
$$V_n = V_{n-1} + a_{n-1}\Delta t \quad (8)$$
$$a_n = a$$

The projectile motion of an object is simple to analyze is we accept that (1) there is no air friction and (2) gravitational acceleration (g) is constant over the range of motion. When we get to this stage, we get the projectile motion as the combination of two simple shots: vertical and horizontal. The vertical component of the projectile motion is the free-fall. According to our second acceptance, the value of the gravitational acceleration is 9.8 m/s^2 in order to easy calculation.

MODEL

The developed model offers three different data entry options. Besides, each option offers the option of whether there is air friction. There are no other forces to cease or decrease the initial force except air friction in our environment. This problem is called “projectile movement with air resistance”. In the first option, the system requires the initial velocity (V_0) and the initial angle (Θ). The second option requires V_x and V_y velocities. Unlike these options, the third option requires the initial angle and point where the motion will end, which is the range (x).

The first option works on the motion if only the V_x initial velocity on the X-axis and the V_y initial velocity on the Y-axis are given as in Equation (9). The initial angle can be calculated as in Equation (10).

$$V_0 = \frac{V_{0x}}{\cos\Theta}$$
$$V_0 = \frac{V_{0y}}{\sin\Theta} \quad (9)$$

$$\arctan\left(\frac{V_{0y}}{V_{0x}}\right) = \Theta \quad (10)$$

In cases of there is air friction, the developed model needs the air friction force (F_d) value. As mentioned in Chapter 2, the model needs other parameters. As it is known, the force equals the multiplication of the acceleration and the mass according to Newton’s second law ($F = ma$). In light of this law, the values of acceleration (a) on the X and Y axis can be calculated as $a_x = F_{dx}/m$ and $a_y = F_{dy}/m$. The last parameter is the time interval (Δt). Now we can find the range (x) by placing these values in Equation (8) for each time.

If there is no air friction, calculations are more simple. The range (x) of the motion is calculated using the basic range equation ($x = V_{0x}t$). However, we do not know the total time of motion. Indeed, we can find total time using $t = 2V_{0y}/g$. The maximum height of the motion (h) can be found using $h = V_{0y}\mathrm{t} - ({gt^2}/{2})$.

The second option is easier than the first option. Equation (10) is not needed because the initial angle and the initial speed are known. The range calculation is the same as the first option.

The third option works on when there is no air friction. Because of the nature of the projectile motion, position changes in each time interval are the same amount. Differently, when there is air friction there is no mathematical formula to solve the third option.

The developed virtual laboratory allows the user to keep track of all the motion. Whenever s/he wants, the user can pause the motion and examines outputs of the paused situation.

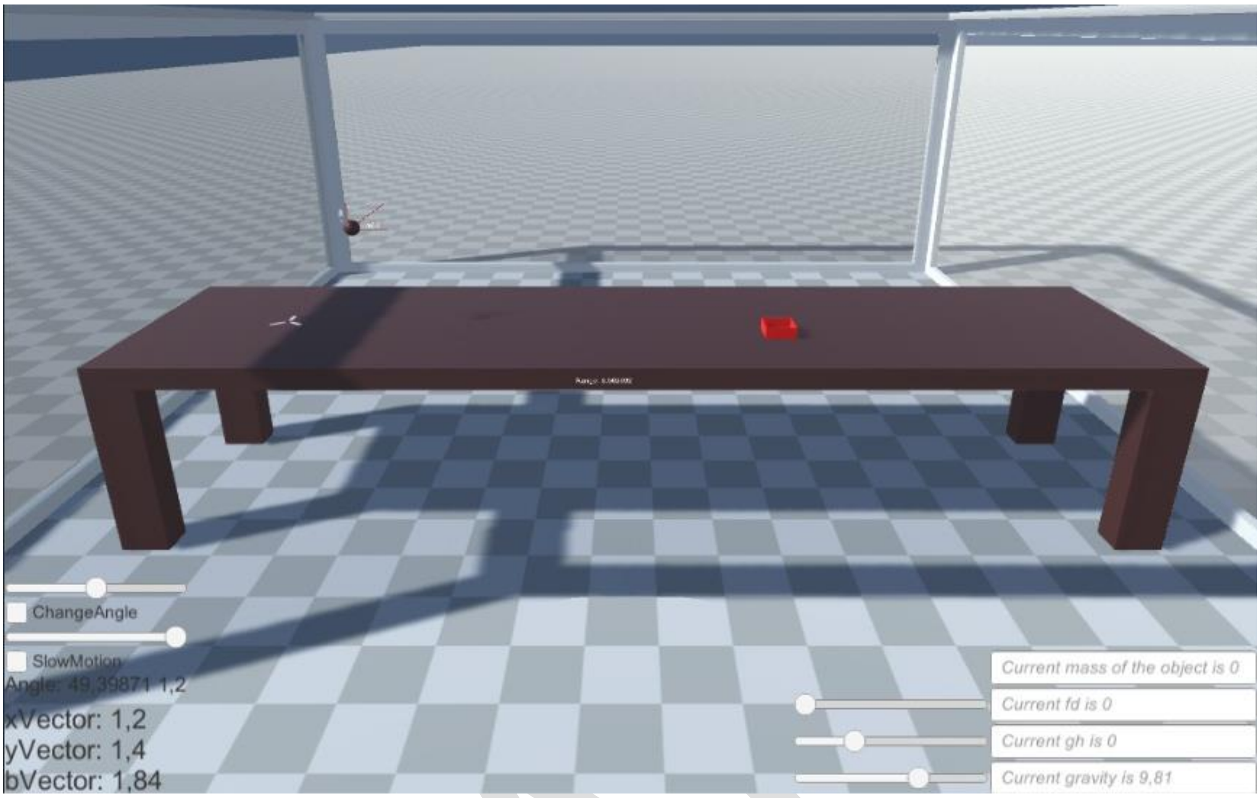

Figure 3. An example of the experiment setup

We can see the main setup of the experiment environment in Figure 3. On the left bottom of the screen, the user can adjust the initial angle. The red box on the table is the goal of the motion. Its location is determined according to initial parameters. The user can see the range of the motion center of the table as in Figure 4.

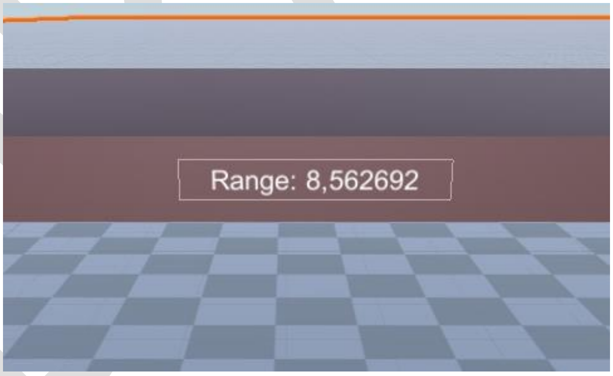

Figure 4. An example of the range of a projectile motion

The user can pause the motion whenever s/he wants and see the recent velocity and vector of the projectile as in Figure 5.

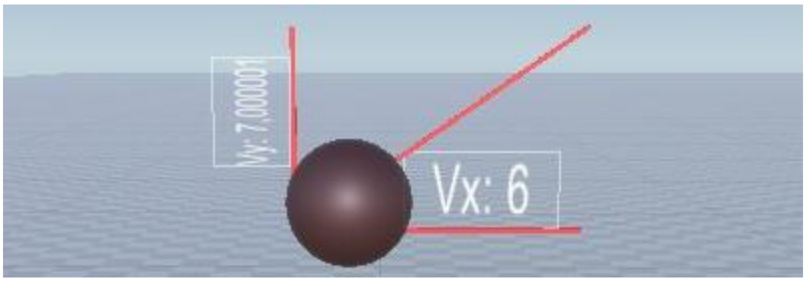

Figure 5. An example of the recent values of the projectile

CONCLUSION

This paper introduces a virtual laboratory for mechanics physics experiments. To test the developed virtual laboratory, especially, the projectile motion problems are used. The developed system, firstly, offers to choose an approach method. The first option gets two components of initial velocity, the second option gets initial velocity itself, and the third option gets the ending point of the motion from the user.

Secondly, the system provides the user with the option of air friction. Calculations vary depending on whether air friction exists. The proposed method, Euler's mathematical method, provides us all possible situations of the motion. Our system works very well and shows the whole nature of the movement.

The robustness of the system is measured by how accurately it gives the results. Especially when there is air friction in the system, the comparison between the results of each execution of the motion shows us if the time interval between each calculation step is narrowed, more precise results are obtained. In other words, this narrowing brings us closer to the true nature of the motion. As in Table 1, air friction changes the range of the motion. On the other hand, as we mentioned before, the initial velocity of the motion, when there is air friction, cannot be found if we have only the range information.

This study proposes a model for those interested in physics to perform experiments in anywhere with a computer system. On the other hand, more user-friendly systems can be developed. Computer hardware technologies are constantly evolving. With the help of the latest improvements in virtual reality (VR) technologies, the developed model can be used with a VR device. In this way, the user can affect the motion directly in a three-dimensional virtual environment.

Table 1. Results of the developed system

		WITH AIR FRICTION	**WITHOUT AIR FRICTION (D = 0.5)**
1ST OPTION	$V_{0x} = 40$ $V_{0y} = 69.3$	Range = 174.4m	Range = 565m
2ND OPTION	$V_0 = 80$ $\Theta = 60$	Range = 174.4m	Range = 565m
3RD OPTION	Range = 565m $\Theta = 60$	-	$V_0 = 80$

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