Original Article

Application Of Physics Model In Real-Time Bouncing Animation

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Abstract

This study investigates the application of physics algorithmic in achieving realistic time based animation. In order to produce realistic animation, the accuracy of timing adhering to the basic laws of physics is an extremely important to be included for the calculation. Based on the review, it would seem that creating realistic timing simulation in animation would be significantly difficult particularly in setting keyframes. It is often time consuming to setting the value frame by frame and estimating the correct timing to simulate a motion. Therefore, a case study of bouncing balls' simulation is carried out with the application of physics formula, in order to produce a real time animation. Experiments have been carried out on different materials of the bouncing ball and different floor types. The results show that animation-based physics concept provides the animator the ability to control the realism of animation without setting the keyframe manually to achieve realistic-timing simulation.

Keywords: Animation, Bouncing Ball Simulation, Physics, Real-Time Animation

1. INTRODUCTON

The physics-based approach is a well-adapted concept in order to simulate the realistic looking animations. Nowadays, the concept of applying the laws of physics in animation has further gained importance with the advent of technology. Acccording to Garcia, Dingliana & Sullivan (2008), as the quality and accuracy of physics engines increases, there has been some demands for going beyond just accurate physics and incorporating artistic variations to interactive real-time simulations. Futhermore, Robertson (1998, 1999, 2001a, 2001b), explained that to transform vision into a realistic animation, the animator defines desired behaviour in precision and constructs motions that appear realistic. The results of physics based simulation techniques show excellency in generating realistic motions and the techniques have become widely adopted in the computer animation industry lately. Hence, to generate a realistic and accurate timing animation, there is a need of consideration of physics motion.

The concept of physics motion can be interpreted in relation to the principle of bouncing ball simulation. According to Heck, Ellermeijier & Kedzierska (2008), Newton's laws of motion and concepts of gravitational energy and kinetic energy, with examples of objects dropped or thrown vertically, contain investigative activities about free-falling objects study. However, in the opinion of Williams (2009), the concept of bouncing ball is often used and it shows many different aspects of animations. The simulation of bouncing ball includes the principles of squash and stretch, arcs, momentum, timing, key drawings, in-between drawings, weight, speed, and the substance of an object. The two basic elements of animation in bouncing ball simulation is shown as below:

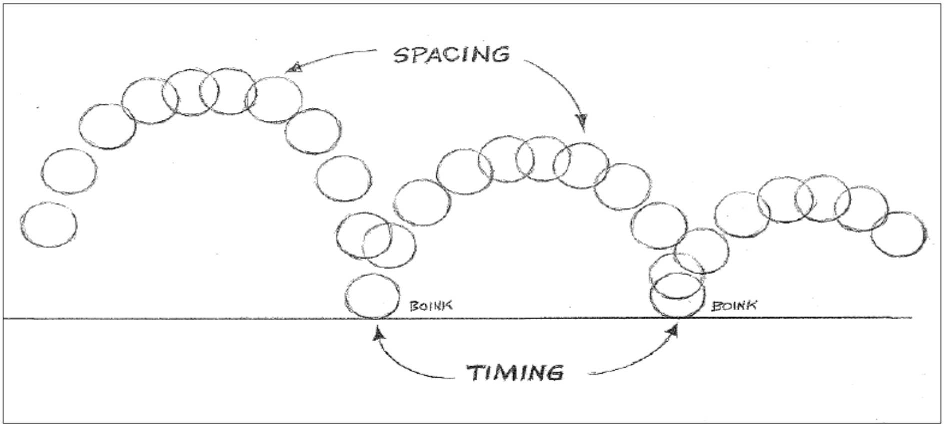

Figure 1: The Two Basic Elements of Animation by Williams (2009)

Figure 1 shows two basic elements of animation which are spacing and timing. Williams (2009), explained that when a ball hits the 'Boink' point, that is the timing. The impacts show when the ball is hitting the ground and that is the timing of the action. On the other hand, spacing is shown when a ball overlaps itself at the slow part of its arc, but when it drops fast, it is spaced further apart. The spacing is how close or far apart those clusters are.

Bouncing ball is the most basic of all animation exercises and one of the most important. From this simple action, it can indicate timing, squash and stretch, arcs, volume and weight. realistic bouncing ball simulation showed the significance in the animation that a lot of physical measurements are required. In realistic-bounce animation, however, the most important aspect of the principle is the fact that an object's volume does not change when squashed or stretched. As real objects, the realistic motion of a bouncing ball needs to be considered with the bounce characteristics, and they are mass (m), acceleration (a), velocity (v), time (t) and gravitational force (F). This can be determined by laws of motion, Newton's laws of motion, and Hooke's law. According to Cross (2006), the dynamics of a collision can be determined between a ball and another object, in principle, from the initial conditions and the functional form of the force acting on the ball. If the collision is elastic, it can be determined by Newton's laws of motion, F=ma and Hooke's law, F = kx, where x is ball compression if the force acting on a ball and the collision is elastic and the springiness or rigidity of an object is k. The collision of a ball always involves some loss of energy. The coefficient of restitution (COR) has been measured for many objects and surfaces on the energy loss when the force acting on a colliding ball.

Timing an animation is often the most difficult part to set the spatial values of the keyframe in achieving realistic simulation. Most of the users are unable to imagine the timing and convey it using the provided interfaces. Hence, based on physical motion regarding numerical simulations, an algorithm model for fast and physics-based accuracy simulation will be developed, in which the animator is provided with the ability to control the realism animation without setting the keyframe. Using this physical framework, the real-time animation can be addressed using this method for controlling the motion of simulated object.

2. LITERATURE REVIEW

Based on Wong and Datta (2004), realistic animations focused on creating realistic images and animations that mimic the world we see around us, as well as creating believable environments not from this world. Since the earliest form of cartoon animation, animation artists have carefully studied the motion of the objects by adding the quality and accuracy to generate realistic looking animations.

According to John Lasseter (1987), the 12 basic principles of animation is a set of rules introduced by Disney's Nine Old Man, who were the core animators of Walt Disney Productions, to produce more sophisticated and realistic animation. The principles of animation are squash and stretch, anticipation, staging, straight ahead and pose to pose, follow through and overlapping action, slow in and slow out, arcs, secondary action, timing, exaggeration, solid drawing and appeal. These principles are important to be applied to visually improve the accuracy of object motion in animation. He also explained that proper timing is crucial to making the ideas readable. Proper timing plays an important role in simulating realistic animation. Timing defines the weight, mass, size, shape, acceleration, velocity, air resistance, gravity and force of an object behaviour. However, animator must engage the Laws of Motion in making a realistic timing animation by taking the consideration on these object behaviours.

Hahn (1988), explained that a real object in a scene cannot avoid consideration on physically based illumination while planning the motion to be appeared realistic. We need to justify objects' properties in a scene as real objects that have mass, moment of inertia, elasticity and fiction. In order to achieve the realistic animation, the physically based illumination of objects properties cannot be avoided in planning the motion animation for ensuring the realism.

Moreover, Terzopoulost (1991) described physically-based techniques facilitate the creation of models that is capable of automatically synthesizing complex shapes and realistic motions. Physically-based modelling presents graphics objects to geometry shapes which include forces, torques, velocities, accelerations, kinetic and potential energies, heat, and other physical quantities that are used to control the creation and evolution of models. In the study, Terzopoulost stated that simulated physical laws govern model behaviour, and animators can guide their models using physically-based control systems. He also mentioned that physically-based models are responsive to one another and to the simulated physical worlds that they inhabit. The physically-based modelling is a very useful technique in simulating a real world model in animation using computer graphics.

On the other hand, realistic bouncing ball simulation shows significance in the animation that requires a lot of physical measurement. According to Whitaker and Halas (2002), the real criterion for timing animation is to have the knowledge on physics laws of motion. He stated four important points in simulating a realistic falling object's motion. First, the greater object's mass, more force is required to change an object's motion. Second, gravity will influence the speed of a ball by rising gradually diminishes to zero. Third, all the objects fall with the same acceleration, which is about 9.8 meters per second by disregarding the air resistance. And forth, when an object is dropped with the average weight, then the distant it falls in a time with acceleration. Based on the four points that stated by Whitaker and Halas, a realistic falling object's motion formula need to measure in terms of the force (f), gravity (g), distance=displacement (d), time (t), acceleration (a), mass (m) and speed=velocity(v). All the terms mentioned by Lasseter deal with formulas in physics law of motion.

A real time animation system is a tool for animation that requires accurate images on display device. Real time system must respond within strict constraints because once the system is given an input, it must produce an output within a precisely-defined period of time, ranging from a few milliseconds (Ben-Ari, 2009). Therefore, to achieve real-time performance, the simulation time must always be synchronized with the physical time and produce an output precisely within strict constraints, regardless of computational platform. Understanding the principles of animation, physics law of motion and the factors will create a believable movement of everything in animation to appear realistic from bouncing balls to characters. In animation, every movement created is based on what actually happens in nature. The study will take into account of basic principles of animation and physically based object's factors in which to be consistent with the laws of physics in generating realistic looking animations. Based on physical motion regarding numerical simulations, an algorithm formula and physically based accuracy simulation will be developed to provide the animator with the ability to control the realism of animation.

3. METHODOLOGY

Video analysis of recorded experiments was carried out by researcher on several common ball types to study the different bounce characteristics. Results are presented for a tennis ball, a squash ball, a basketball, a golf ball, a metal petanque ball, and a rubber ball which are shown in Figure 2. The metal petanque ball was studied as an extreme case of a ball with a low coefficient of restitution, since the collision is totally inelastic, and the rubber ball was studied because it has elastic properties. The first four balls were studied because of their ordinary use in animation. The balls were being bounced vertically without spin on a hard, horizontal surface. Four types of hard surface experimented in this method include cement floor, carpet floor, parquet floor and laminated floor as shown in Figure 3. The experiments were carried out with the objects in free fall. When the object is in free fall, only gravity acts on the object (neglecting the factor of air resistance).

Types of balls	Weight
A: Basketball	620 grams
B: Petanque	750 grams
C: Tennis ball	56.7grams
D: Rubber ball	350 grams
E: Golf	45.93 grams
F: Squash ball	25 grams

Figure 2: Type of Balls used in Experiment

Figure 3: Type of Floors used in Experiment

In the experiments, each ball was dropped from the height of 1 meter to the floor (hard surface) to determine time and height of the ball would bounce. A video recorder and stop watch were used in this experiment. All the experiments were recorded as as the number of seconds between bounces of the ball was timedwhile the height of the ball bounces was observed and recorded. The height and duration were recorded in the data chart. The experiment was repeated for a total of 10 tries for each ball to gain accurate data.

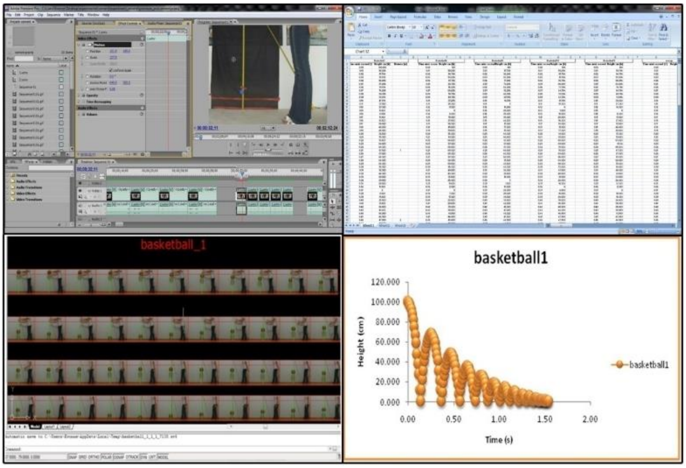

Figure 4: Screen shot of Progress Measurement on Bouncing Ball Experiment

Next, the videos recorded were rendered to frames by using Adobe Premium Pro. The frame rate of every video was rendered by every 30 frames per second (30 fps). Every frame was calculated in the Autodesk AutoCAD to have an accurate measurement. All the data was then transferred to Microsoft Excel (refer to Appendix E) and the real motion of bouncing balls was analyzed. For each ball, a dynamic hysteresis curve was presented to show how energy is lost during and after the collision. All the results are transmitted into graphs as presented in Figure 4.

4. RESULTS AND DISCUSSION

The results of the dynamic bouncing balls bounce on different floors are shown in the graphs below.

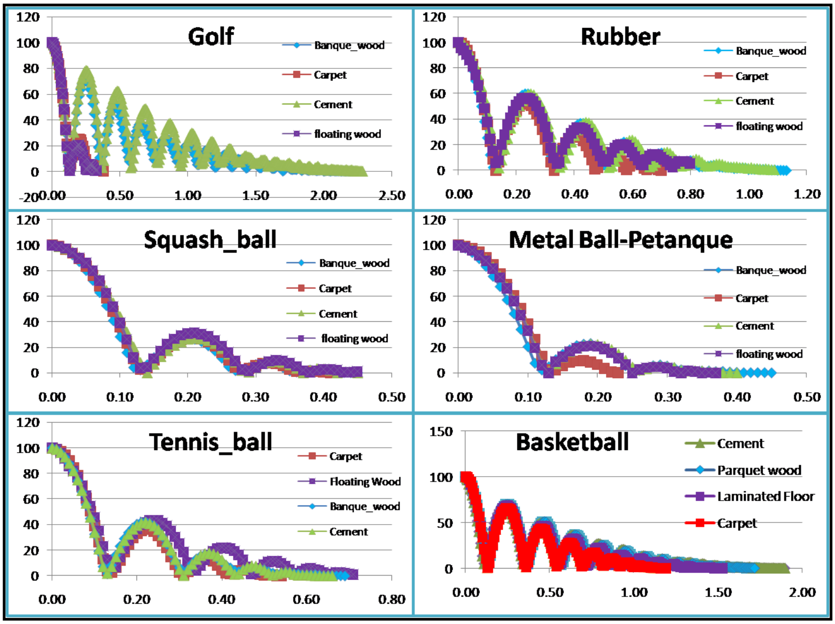

Figure 5: The Results of Dynamic Bouncing Ball Bounce on Different Floors

The graphs in Figure 5 represent the results of dynamic bouncing ball bounce on different floors. A graph consists of x-axis and y-axis which correspond to the variables of height (cm) and time (s) of a ball bounce. From the graphs, it can be observed that different types of floor will influence the dynamics of the bouncing ball. Most balls' bouncing takes longer time with harder surface such as cement and parquet wood floor. Conversely, bounces of the balls take shorter time with softer surface such as laminated and carpeted floor.

The results from the graphs implied that energy is absorbed into the ball that makes the ball bounces higher on hard surface and takes longer time for the ball to stop; however, if the ball bounces on a soft surface, the energy is absorbed into the surface and makes the ball bounces lower gradually and takes shorter time to stop bouncing. Thus, the energy loss happens on the colliding ball when it bounces and hit the floor surface. It caused the ball to gradually lose height due to the loss of energy. This phenomenon is shown in the graph of every motion of bouncing ball in Figure 5. Hence, we can conclude that floor surface is one of the important factors that influence the bouncing ball simulation.

However still, exception happened in the results of experiments on a squash ball. Referring the graph of squash ball, the dynamic of bouncing squash ball produced almost the same result regards of different types of floors. The reason is the influence of another factor, which is the ball's material. Squash ball is made of a rubber compound, which has fairly low resilience compared to the rubber ball. From the results, researcher found out that the squash ball is consistent and stable when bounced on different types of floor compared to the rubber ball. Hence, it is suitable to be used for the next stage experiment in measuring an accurate algorithm formula for bouncing ball simulation.

Different types of ball consist of different material, size and weight. These variations can influence mass or volume of an object. How mass of a ball influences the dynamic of bouncing ball were analyzed and shown in Figure 6.

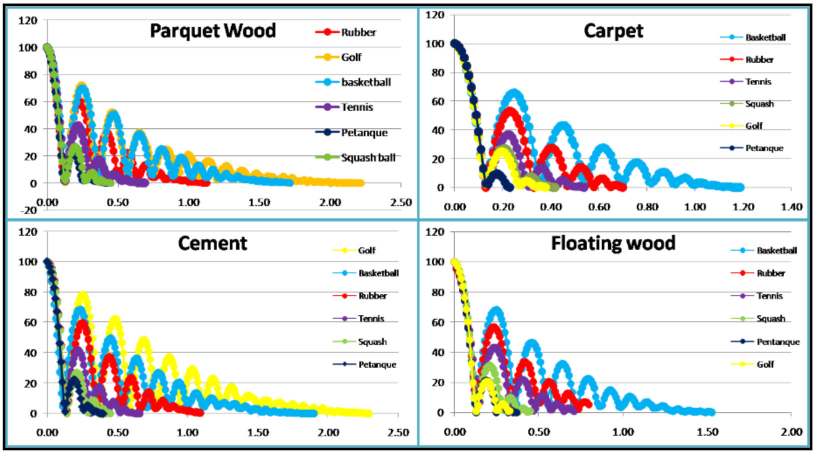

Figure 6: The Results of different types of balls bounce on the same Floor

The graphs presented in Figure 6 show the results of different types of balls bounce on the same Floor. A graph consists of x-axis and y-axis which correspond to the variables of height (cm) and time (s) of a ball bounce. From the graphs, results show that types of ball would influence the dynamics of the bouncing ball, although they are bounced on the same floor. Most of the lower-weighted balls such as basketball, rubber ball and tennis ball bounce in higher height which takes longer time to stop bouncing. Conversely, higher weighted balls such as metal petanque ball, squash ball and golf ball bounce in lower height with shorter time to stop bouncing. But then again, exception happened in the result due to other factors such as surface of the floor. It is clearly shown in the golf ball's bouncing graph, that it takes longer time bouncing on the parquet wood and cement floor.

Overall, the results from the graphs implied that the material of a ball which is not close to being perfectly elastic has absorbed energy that cannot be converted back to kinetic energy. The heavier the ball such as metal petanque ball, the faster it is moving and the greater the impact when it hits on the ground. At the same time, it provides greater potential energy. Thus, there is nowhere for energy to be stored before the bounce, so more of it will be wasted and transferred into heat and sound energy. The ball will then bounces back in lower height and stop within short period.

On the contrary, the heavier the ball is with the material which is close to being perfectly elastic moves faster, and the faster it moves, the greater its impact on the ground which brings more absorbing of energy into the ball. Thus, the ball will bounce higher on the surface and takes longer time to stop bouncing. Again, from the research findings, we can conclude that the heavier balls will bounce in higher height with longer time if the material of the ball is elastic and vice versa. Hence, the ball's mass is one of the important factors that influence the bouncing ball simulation.

Based on the finding and validation of the research, a finding model was derived from the conceptual framework. The basic physics motion is essential in achieving realistic time based animation. It is used as a fundamental for basic understanding in the physics measurement. In order to get realistic timing and spacing, we need to consider physics factors and follow the physics laws of motion.

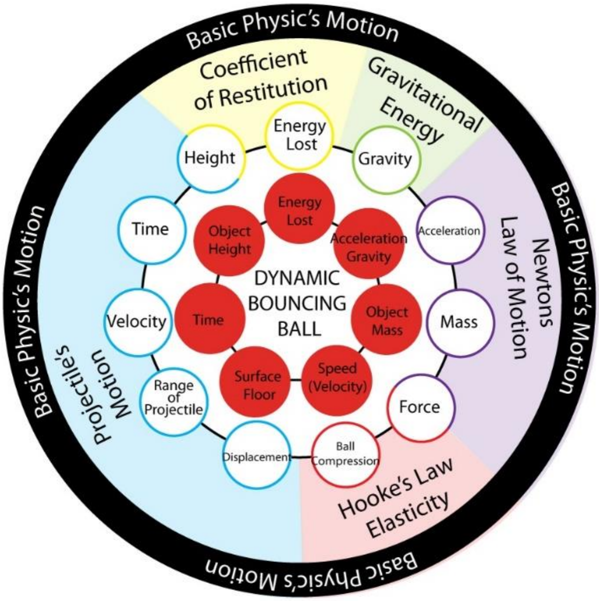

Figure 7: Physics Model in Simulating Real-Time Bouncing Animation

A finding model was developed, as shown in Figure 7, to comprise a broad concept on performing physics time based bouncing ball animation. It is an important stage to follow the related physics laws of motion and to determine the accuracy in the movement of falling object. For dynamic bouncing ball, we need to understand the gravitational energy, Newton's law of motion, Hooke's law elasticity, projectile's motion and coefficient of restitution. The concepts of these six physics laws of motion contain investigation on bouncing ball's motion.

In the meantime, the physics laws of motion derive eleven relating major factors and influence the realistic dynamic of bouncing ball in motion. These physics factors are height, energy lost, gravity, acceleration, mass, force, ball compression, displacement, range of projectile, velocity and time. However, the research studied on these eleven major factors has proved that, the consideration on the seven major of physics factors is enough to achieve realistic time based bouncing ball animation. The result findings show the important of seven major factors in formulating a realistic dynamic for free fall dropping object. They are energy lost, acceleration gravity, object's mass, speed, surface floor, time and object's height. The result findings prove that the use of physics formula by considering these factors would achieve realistic dynamic of bouncing ball animation, and also both physics based realism and user-specified expressive motion.

As a result, it is also proved that the performance of physics time based bouncing ball animation can be achieved by following the model shown in Figure 7. The finding model can be presented as a guideline to the animator as a tool for generating the physics based realistic movement.

5. CONCLUSION

In animation, realistic timing is extremely important to add a life-like quality to animated objects, making their motions more interesting and able to convince the realism as well as convey the message to the audiences. However, timing an animation is challenging to set the spatial values of the key-frame in achieving realistic simulation. It causes burden of animation quality rests entirely on the animator. The case study of bouncing balls simulation was carried out and the use of physics algorithms formula is analysed in order to achieve realism in animation without setting key-frames values. The literature review of this research includes concepts of physically based animation which is made up of major elements such as realistic animation, concept of physically based animation, bouncing ball simulation, law of physics motion and real time animation. The physical object factors include acceleration gravity, object's mass, surface floor, object's height, energy loss, speed and time of the dropping object in motion, were also discussed. From the review, a physically based illumination of object properties models was derived. It is essential as a factor in the physics formula calculation. The finding shows that the understanding of principles animation, physics law of motion and physically factors of objects properties will create a believable movement of everything to appear realistic. Moreover, it is possible that research in future on physics based algorithm animation can be expanded to other objects or characters such as human or animal motion, human face expression, fluid or fur object. This approach should be generalized to deal with other objects, so that a wider variety of controllable physics based realistic animations can be achieved in future.

6. ACKNOWLEDGMENT

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