Virtual Domino: Interactive Physics Simulation and Experience

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요 약

Virtual Reality simulation enables immersive 3D experience of a Virtual Environment. A simulation-based VE can be used to map real world phenomena into virtual experience. This research studies on the use of Newton's physics law to demonstrate the effects of forces upon object's falling movement, and their effects towards other fallible objects. A reconfigurable simulation enables users to reconfigure the parameters of the objects involved in the simulation, so that they can see different effects from the different configurations, such as force magnitude and distance between objects. This concept is suitable for a classroom learning of physics law.

Preliminary implementation is done on a PC with a joystick for 4DOF movement. The graphics is implemented by SGI OpenGL Performer. A middleware called NAVERLib that consists of Performer's modules for easy XML-based configuration is used for management of visualization, network and devices connection, and where the engine of this domino simulation is attached.

Keyword : Interaction, VR, Simulation, Education

1. Introduction

In recent years, there is an increasing use of Virtual Reality (VR) technology for the purpose of immersing human into Virtual Environment (VE). Many cases have benefited from VR technology, for the purpose of fun, training, and education. These are followed by the development of supporting hardware and software tools such as display and interaction hardware, physics-simulation library, in order to have more real experience with more comfortable hardware.

In educational science, there is a concept called "meaning by doing", which means that resulting knowledge creation is unique to the individual, which is called constructivist principle [1]. This principle indicates that a student can gain more knowledge through the experience of building the knowledge itself, not just receiving instructions about the knowledge. By this principle, a student who participates in planning and design phase can experience simulation based on what he/she has designed or configured, not just experiencing simulations with a pre-designed set of parameters. This is why a reconfigurable simulation is needed for educational purpose.

Moreover, a sense of presence is especially useful in science learning [2]. This sense of presence exists in VE, which is enabled by the use of VR technology. By immersing a user in a VE, he/she can sense the presence of nature's law, such as physics law. Therefore, constructing a scientific simulation in VR can help user to experience nature's law and gain understanding from the experience.

Even though VR technology does not provide significant difference in promoting student's understanding of a science lesson [1, 2], it definitely promotes motivations for students in learning such science. VR has brought dynamic and interesting visualization so that users feel easy to understand what is going on in the simulation. Meanwhile, there are still more aspects to be investigated in creating a useful VE, such as the use of color, texture, and sound in the scene designs, the use of suitable haptic devices, and the target age group of the users.

According to a research [1], the best age group to use VR-based simulation for science learning is middle school students (around 13 years old). Therefore, science on that level needs to get more attention to be realized into VR systems. The Domino Simulation is a good example of simple science for young teenagers. This simulation focuses on physics learning especially Newton's law of dynamics (force-related). In this paper, we will explain what can be experienced by users of Domino Simulation. Moreover, the simulation is reconfigurable by users, so that they can experience different simulation environment due to different configurations they make.

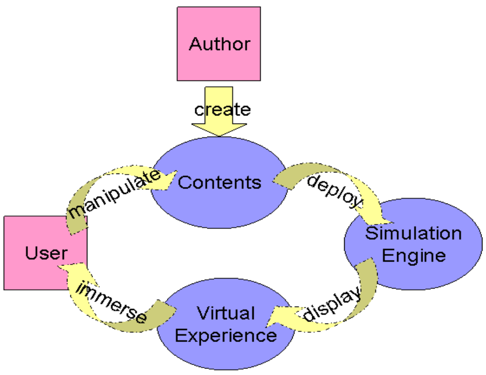

Fig. 1. Interaction between Author and User in the simulation and virtual experience process

This paper is organized as follows: Section 2 describes related works in order to see the need of this research; Section 3 explains the design of the simulation; Section 4 describes the system implementation, and the results are presented in section 5; Finally, Section 6 brings out the conclusion of this research.

2. Related Works

According to our experiences, there is no such physics-based simulation in immersive VR applications that has been focused primarily on educational purpose. Our research is trying to cover that part, while past researches have covered educational VR, educational physics simulation, and physics-based VR simulation.

2-1 VR and Education

Several researches have been done in the field of employing VR for educational applications. The NICE Project [3] has implemented a virtual learning system for children. The system works according to specific narrative generator, where children can participate to be the characters in the stories they create themselves. By generating stories, children learn in a constructivist way. This system also includes a support for collaborative learning, where children can track each other's presence in the virtual space using avatars. Moreover, children from other space can take parts in the collaboration through web-based version of the narrative generator. This is an example of the use of VR for immersive educational environment.

2-2 Physics Simulation

Physics and other science formula sets have been implemented by several researches in simulation applications. Physics simulation for cooperative learning [4] enables students to learn dynamics physics through simulation. This system includes parameters adjustments, which means that it is a reconfigurable one. However, this system is a web-based one, not VR-based.

Interlude [5], a game edutainment, is focused on dynamics experiment simulation, which means that it helps users to learn physics. It provides sound effects for more realistic experience. However, the system is implemented on a standalone computer with Human Interface input devices, which limits the degree of immersion of the users.

For VR-based applications, this physics-based simulation [6] was developed in order to deliver more immersive and realistic experiences in virtual environments. This system especially focuses on rigid body physics simulation triggered by several hap-tic devices. The rigid body physics simulation is actually very suitable for a domino simulation, but this system is still particularly suitable for impulse and momentum-based physics simulation. Therefore, for a soft movement like in the domino pushing, this system is not suitable, because users are not interested in seeing the momentum and impulse law.

3. Simulation Design

The simulation consists of several domino blocks that are put together to form a line. Students can push any domino blocks to see the effects that the pushed block gives to other blocks. Timing of the simulation process can be recorded, and the state of the simulation can be reset to the original state where all domino blocks are put back into their original positions before the pushing action.

3-1 Physics Concepts

We provide simulation for Newton's Law of Force, where students can learn the effects of the different parameters used in the formula. The first formula is $F = ma$, where m is the mass of a single domino block, and a is acceleration of the pushing movement. This F is the magnitude of the horizontal force applied to the pushed domino block.

The second formula is $F_f = nmg$ where m is the mass of a single domino block, and g is gravity value (default: 9.8 m/s$_2$). The mg calculation is the weight of the domino block downwards, which is affected by gravity. The coefficient n is the friction coefficient of the floor. It is multiplied with the weight to get the value of friction force. Since the friction force is upwards (opposite value to the downward weight), then the total vertical force $F_v = (1- n)mg$.

A force resultant F_r is the final force magnitude that is applied to the pushed domino block. It comes from the calculation of the horizontal (user's force) and vertical force using the Pythagoras' right triangle theorem. This final force can be shown to students so that they can confirm their calculations.

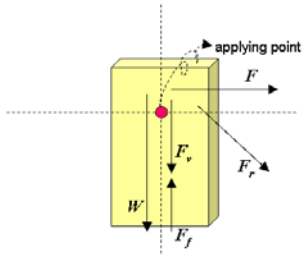

Fig. 2. Different forces acting upon a domino block when a user gives a force F

Timing can also be recorded so that users can experience the effects of different forces on the speed of the falling movement of the domino blocks. The distance between domino blocks also affects timing, because with the same speed the time taken to touch the next domino blocks differs as the distance gets further. In here, the kinematics law of $s = vt$ (distance equals to velocity multiplied by time) can also be observed.

3-2 2D Simulation

As a first prototype, a 2D simulation environment is designed for web-based simulation. With SVG [7], an XML-based graphics, a set of domino blocks is lined up. However, this simulation can only work by mouse-click, therefore it is not suitable for force representation. The simulation can then only be measured by time, not by force. Moreover, in 2D scene users cannot see the push direction and eye orientation towards the objects.

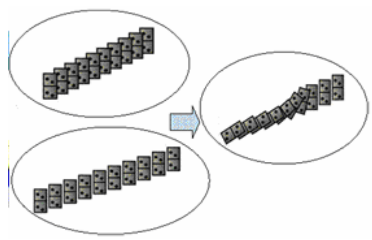

Fig. 3. 2D domino simulation with different configuration of distance between blocks

3-3 3D Simulation

To overcome the limitation of 2D scene, a 3D model was constructed. A 3D model of domino simulation scene was created. The scene consists of a hand avatar, domino blocks, and a ground (floor). The eye orientation is configured to enable an angular 3D view so that users can see the domino block's 2 sides and the movement of the hand towards the to-be-pushed domino blocks. With the addition of joystick, user can move the hand avatar more freely than just a mouse click.

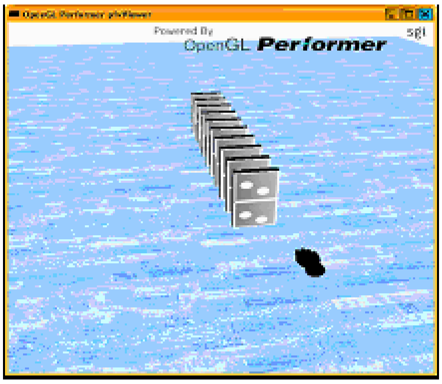

Fig. 4. 3D domino simulation with floor and hand avatar models

4. Implementation

SGI OpenGL Performer [8] is used in implementing this application, since it is one of the popular graphics programming tools for VR applications. The application is programmed in C/C++ language in Microsoft Windows environment. To enable the push movements in 3D space, a joystick is used, because it has 4 degrees of freedom (DOF), which includes front, back, left, right, up and down movements plus rotation. This joystick is equipped with force feedback to enable vibration when the user pushes the domino. VRPN server [9] is executed to provide the connection of the joystick for VR applications.

4-1 Configuration

To enable easy XML configuration, the application is implemented in modular way. The module is then called by pfvViewer, one of the tools of SGI OpenGL Performer. With this tool, a VR application can accept parameters from what are written in the XML file (with .pfv extension). The Domino Simulation application has several configurable elements in the XML file that is read by Performer's engine to be passed as parameters.

```xml
<module>
    <class>nvmDominoSimulation</class>
    <data>
        <id>physics</id>
        <gravity>9.8</gravity>
        <!--mass of each domino block-->
        <mass>200</mass>
        <!--distance interval between domino blocks-->
        <distance>0.7</distance>
        <!--friction coefficient of the floor-->
        <friction_coefficient>0.2</friction_coefficient>
        <!--the smaller the number, the slower the animation-->
        <frame_step>0.005</frame_step>
        <!--reset animation without re-executing pfv file-->
        <reset_key>r</reset_key>
        <!--freeze animation at anytime-->
        <freeze_key>s</freeze_key>
        <!--freeze animation at a given time-->
        <freeze_time>0</freeze_time>
    </data>
</module>
```

Fig. 5. Configurable elements for Domino Simulation application

In Figure 5 above, gravity of the world and the mass of a single domino block can be modified. With the friction coefficient configuration, the Newton's law can be observed. The distance between each domino blocks can also be configured in order to enable time observations. Some convenience purposes were also designed, which are the reset key for returning all objects to their original states, freeze key for freezing the animation at the desired time, and frame step to view the simulation in a slower pace, so that users can observe more carefully.

4-2 Middleware

We use NAVERLib [10], a middleware used for managing several VR tasks such as device and network connections, events management, specific modeling, etc. We use nvmDisplayManager to enable simultaneous display in more than one computer. This is useful when we need to run this application in CAVE [11] like systems or for distance collaboration. The module nvmDeviceManager is used for managing connections to device server such as VRPN and get the lists of devices attached to it. To enable stereo graphics (dual display buffers to enable 3D projected scene), the module nvmASVF is used. The module nvmDominoSimulation is the implementation of the simulation engine for physics law in VE. Some NAVERLib data structures are used to provide shortcuts to using Performer's functions or supplementary functions. An example of NAVERLib's data structure is nvText that is used for easy displaying of Performer's text object on the scene graph.

5. Experimental Results

A user was presented with experience to try experiments on the simulation parameters. First of all, the user changed the distance parameter, so that the user can view the different visualizations between the configurations, as seen in Figure 6.

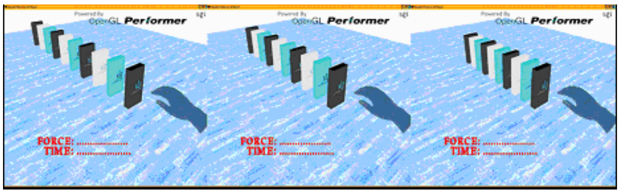

Fig. 6. The visualizations after distance configurations: long, medium, short

The user then tried to start simulation on the different distance configurations, and she froze the scenes to observe the state of the simulation at the given time. The state of the simulation at time 1.2s after the force application can show the effects of the distance configurations, as seen in Figure 7.

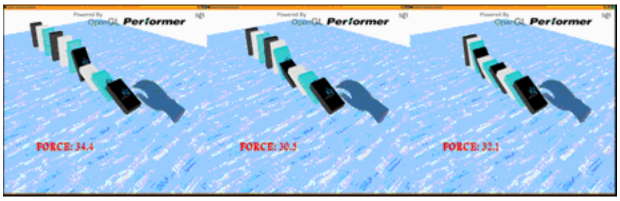

Fig. 7. Simulation position at time 1.2s after similar-magnitude force application: long, medium, short distance

At the third time, the user tried on several force magnitudes, and she made high, medium, and low force magnitudes for each distance configurations. The timing was observed to see difference between them. The time taken is recorded after all domino blocks fell down. The maximum force that can be produced due to the maximum velocity of the joystick is displayed so that user can take note.. The unit for this force is one of the research issues. It can be adjusted from the scaling of the calibration of the joystick's velocity. If the calibration is set to m/s^2 then the force is set to N (Newton).

The user could construct a table like the one in Table 1. Using a table like the one below, user can then deduce and make a summary on the effects of force and distance on the time taken by the simulation.

Table 1. The effects of different forces on different distances between domino blocks, measured by time taken (in seconds)

Force	Long Distance	Medium Distance	Short Distance
Low	3.731	2.788	1.956
Medium	2.830	1.983	1.248
High	1.872	1.345	0.901

6. Conclusion and Future Work

We have implemented an application for simulation-based virtual experience, based on VR systems and simulation of physics law. The system allows reconfiguration of the simulation elements so that users can see the effects of the different configurations. With the provision of easy authoring systems (modeling and object placement), teachers can author different scenes and specify what parameters can be reconfigured by students as users. With the provision of easy XML editing systems, students can easily configure parameters stored in the XML file.

To increase the degree of immersion, this system needs to be implemented in a CAVE-like system. Input device should also be changed into the one with more realistic use such as SPIDAR [12] or wand. Those haptic devices can be operated by one hand only, thus more suitable for the visualization of using one hand to push the domino blocks. With joystick, the hand avatar's movement needs to be done by two hands to operate two sticks (front-back-left-right-rotation and up-down movements).

We are extending this system for collaborative students and authors to experience or create simulation elements through network. Adding sound through the NAVER-Lib's sound manager can add more real experience towards user i.e. louder sounds for faster movements towards the ground. And most importantly, the inclusion of more physics law like in [6] can produce more realistic virtual experience.

References

[1] Osberg, K.M., Winn, W., Rose, H., Hollander, A., Hoffman, H., The Effect of Having Grade Seven Students Construct Virtual Environments on their Comprehension of Science, *Proceedings of the Annual Meeting of the American Educational Research Association*, Chicago, March 1997

[2] Moreno, R., Mayer, R.E., Virtual Reality and Learning: Cognitive and Motivational Effects of Students' Sense of Presence, *Human-Computer Interaction Proceedings* pp. 65-67, Mahwah, NJ, 2001

[3] Johnson, A., Roussos, M., Leigh, J., The NICE Project: Learning Together in a Virtual World, *Proceedings of IEEE Virtual Reality Annual International Symposium (VRAIS 98)*, Atlanta, 1998

[4] Wu, Y., Chan, T., Jong, B., Lin, T., Liang, Y., A Web-Based Dual Mode Virtual Laboratory Supporting Cooperative Learning, *International Conference on Advanced Information Networking and Applications (AINA 04)*, Fukuoka, 2004

[5] Hanafusa, Y., Tominaga, H.; Yamasaki, T.: Interlude, Game Edutainment Materials for Dynamics Experiment Simulation, *Proceedings of the 2005 International Conference on Active Media Technology pp. 303-304 (AMT 2005)*, Kanagawa, May 2005

[6] Kim, J., Irawati, S., Ko, H., Kim, H., Makoto, S., Integration of Physics Based Simulation with Haptic Interfaces for VR Applications, *Proceedings of HCI International*, Las Vegas, July 2005

[7] World Wide Web Consortium, Scalable Vector Graphics, http://www.w3.org/Graphics/SVG

[8] Silicon Graphics Inc., OpenGL Performer. http://www.sgi.com/products/software/performer/

[9] Taylor, R.M., Hudson, T.C., Seeger, A., Weber, H., Juliano, J., Helser, A.T., VRPN: A Device-Independent, Network-Transparent VR Peripheral System, *ACM International Symposium on Virtual Reality Software and Technology (VRST 2001)*, Berkeley, 2001

[10] Park, C., Ko, H., Kim, T., NAVER: Networked and Augmented Virtual Environment aRchitecture; design and implementation of VR framework for Gyeongju VR Theater, *Computers & Graphics 27*, pp. 223-230, 2003

[11] Cruz-Neira, C., Sandin, D.J., DeFanti, T.A., Kenyon, R.V., Hart. J.C, The CAVE: audio visual experience automatic virtual environment, *Communications of the ACM*, Volume 35, Issue 6 pp. 64-72, June 1992

[12] Sato, M., Development of string-based force display: SPIDAR, *International Conference on Virtual Systems and Multimedia (VSMM 2002)*, Gyeongju, 2002