AC 2009-223: THE DEVELOPMENT AND ANALYSIS OF 3D HAPTIC-AUGMENTED LEARNING TOOLS FOR A DYNAMICS COURSE

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Development and Analysis of 3D Haptic-augmented Learning Tools for Dynamics Course

Abstract

The paper presents the development and analysis of 3D haptic-augmented learning tools for Dynamics course, which is a fundamental course offered in most engineering disciplines. Dynamics is considered to be one of the most difficult and non-intuitive courses that engineering students encounter during their undergraduate study. Haptics, the research and application on the sense of touch and force feedback, provides a novel human computer interface for students to interact with virtual dynamics world to potentially gain a better understanding of the dynamics concepts. Under this assumption, this research started with the identification of key dynamics concepts from engineering teaching experience and converted these concepts into interesting interactive animation with both graphics and haptics learning channels. The developed learning tools have been tested with undergraduate engineering students in Spring 2008 and Summer 2008 semesters. The experimental result analysis provides great input to future improvement and dissemination of the novel teaching methods on dynamics concepts.

1. Introduction

Dynamics is considered to be one of the most difficult and non-intuitive courses that engineering students encounter during their undergraduate study because the course combined basic Newtonian physics and various mathematical concepts such as vector algebra, geometry, trigonometry, and calculus and these were applied to dynamical systems[3]. Dynamics is an important engineering course for three reasons. First, it is essential to have a strong grasp of the concepts covered in the course when pursuing a degree in engineering. Second, it is a required course for many engineering departments and is the first engineering course that covers both difficult and abstract concepts. Third, for many capable students this course can become a roadblock to a career in engineering[8].

Computer-mediated instructional technologies, typically in Virtual Environments, hold great promise for use in educational settings in that they can increase students' access to knowledge and act as vehicles that may promote learning[9]. Traditional Virtual Environments only provides visual and/or audio feedback. Recent advances in Virtual Reality and robotics enable the human tactual system to be stimulated in a controlled manner through 3-dimensional (3D) force feedback devices, a.k.a. haptic interfaces[7]. Virtual Reality / Augmented Reality (AR/VR) technologies have been used widely in the educational settings[5]. Graphics and audio contents are extensively used in these VR/AR educational applications, while the inclusion of a haptic interface is still limited. Williams (2003) utilized a 2D haptic interface for teaching Physics, Statics and Dynamics in Ohio University[13]. Researchers at Hiroshima City University (Japan) have demonstrated their initial attempts in introducing 3D haptic interface into Dynamics Learning System[10]. In this study, 3D haptic-augmented learning tools have been created and used to complement the course materials in Dynamics course.

The rest of the paper is organized as follows. Section 2 describes the development process of the 3D haptic-augmented learning tools. Section 3 narrates the experimental process. Section 4 presents the experimental result analysis and discussion. The paper is concluded in Section 5.

2. Development of the 3D Haptic-augmented Learning Tools for Dynamics

Previous studies in Engineering Education have explored students' misconceptions in Dynamics. The Delphi study was the primary source used by the researchers to gather information from faculties about the difficulty and importance of Dynamics concepts[4]. Delphi studies are conducted with Delphi groups, which consist of members who are not always in contact with each other, but have special domain specific knowledge to share. It makes use of mail or computer systems to send a series of questionnaires to a pre-selected group of experts to analyze a specific problem. To take advantage of a collective opinion, experts refine their thoughts as the study progresses. A study at the Colorado School of Mines conducted used Delphi study to identify difficult to understand, yet important, concepts of engineering[12]. If the misconceptions or alternative conceptions dominate, they make learning complex theories in the Dynamics course very difficult. For example, prior research shows that many students found friction a difficult concept, as they could not see friction force with their eyes, but could realize its existence through the resistance to motion[12]. Another study at Pennsylvania State University was conducted with twenty-five dynamics faculty members with good experience from community colleges to research universities[6]. The conclusion would be that more efficient methods are necessary to teach these difficult concepts. This claim was tested by Gary L. Gray and associates (2003) at Pennsylvania State University when they validated the effectiveness of new teaching methodologies and curricula innovations. They conducted the DCI (Dynamics Concepts Inventory) test to over 450 students at a large public university and at a small private university[6].

Based on the previous research results on 'Dynamics Concepts Inventory'[6] and the authors' teaching experience, the following exemplary Dynamics problems are identified (Table 1).

Table 1 Concepts and Exemplary Problems

#	Concept	Problem
1	Sliding and Rolling Motion	Motion of a block and a wheel on a plane
2	Impulse and Impact	An impact between a bowling ball and a bowling pin, or between two balls
3	Centrifugal and Centripetal Forces	A merry-go-round ride, or Particle waltz
4	Coriolis Acceleration	A slider on a rotating arm
5	Kinetics of Rigid Bodies	A piston-crank mechanism of an internal combustion engine

Corresponding to the key concepts listed in the Table 1, the software tools have been developed as the new learning materials. Open Dynamics Engine (ODE) was used as the dynamics engine to support the computation in our graphics and haptics applications. Open Dynamics Engine (ODE) is an open source, high performance library for simulating articulated rigid body dynamics[11]. It is useful for simulating vehicles, objects in virtual reality environments and virtual creatures. With the geometric and non-geometric properties assigned to them, these virtual objects behave similar to the physical objects in the real world[11]. OpenGL is adopted as the graphics engine. OpenHaptics is adopted as the haptics engine[7]. The haptic devices used in the experiments are five sets of Phantom Omni. The developed materials are described as follows.

Concept 1**:** Sliding and Rolling Motion

There are two cases. The two cases look similar but work differently for the block and the ball. One can feel the friction force with a haptic device.

1) A block moving with an initial speed on the surface from left to right: because of the friction on the surface, the block gradually slows down, until it comes to a full stop. The block slides on the surface all the time.

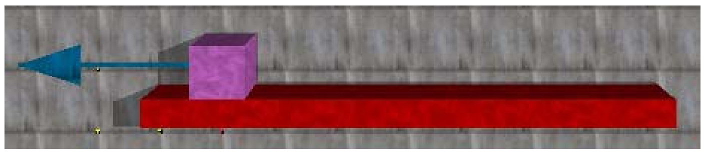

Figure 1 A Sliding Block on a Flat Plane

2) A ball (sphere) with an initial speed on the surface from left to right: because of the friction on the surface, the kinetic energy of linear motion is gradually converted into the kinetic energy of the rotational motion. This means that at the beginning of the motion, the ball is both sliding and rolling. At a certain moment, the ball is no longer sliding as the contact point between the ball and the surface has a zero velocity, which means there is no friction at the contact point. Thus the ball will keep moving at a constant speed. And this motion is pure rolling, without sliding.

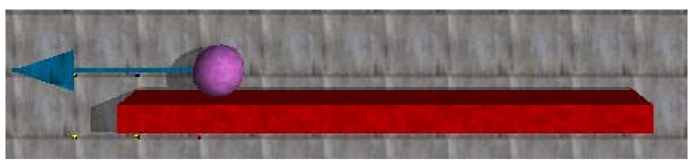

Figure 2 A Rolling and Sliding Ball on a Flat Plane

Concept 2**:** Impulse and Impact

There are two demos for this problem. By manipulating the ball with a haptic device, one can try different impact results.

1) Two (billiard) balls collide with each other: direct impact or oblique impact. By pressing and holding the blue button of the haptic probe, one can drag one ball and try to hit the other

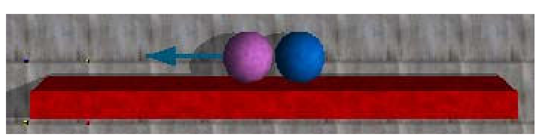

Figure 3 Two Balls in Collision

1) One (bowling) ball hits a (bowling) pin. By pressing and holding the blue button of the haptic probe, one can drag the ball and try to hit the bowling pin.

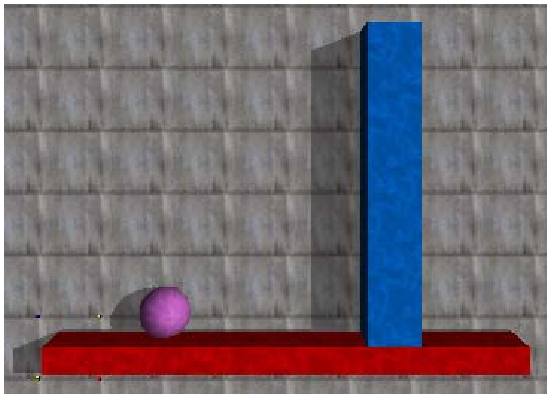

Figure 4 Rolling ball and the Bowling Pin

Concept 3**:** Centrifugal and centripetal forces

This demo shows particle-waltz example. Two particles are used to represent two persons. They are dancing like in a waltz. One particle is leading the other. The other particle follows the motion of the first particle, as if the two are connected with a rubber band. The force arrow shows the magnitude and the direction of the centripetal force. One can feel the centripetal force when dragging the ball with a haptic device.

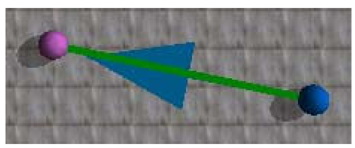

Figure 5 Particle Waltz Example

Concept 4**:** Coriolis acceleration and force

This demo shows Coriolis acceleration and its corresponding Coriolis force. It shows a rotating bar, which rotates at a constant speed. On the rotating bar, a slider block is moving at sine wave motion (autonomously). With a haptic device, one can feel the Coriolis force when following the motion of the slider.

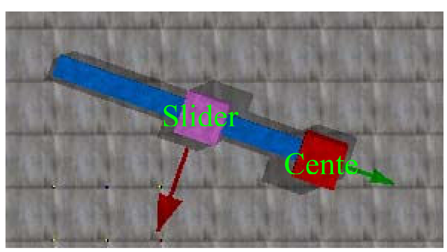

Figure 6 Coriolis Force and Acceleration Example

Concept 5**:** Kinetics of Rigid Body

This demo shows the slider-crank mechanism of an internal combustion engine. Generally speaking, there are three types of planar motion: 1) linear translation; 2) rotation; 3) combined translation and rotation in a plane. In a slider-crank mechanism, the slider is moving at linear translational motion; one link is at rotational motion; the other link is at combined translational and rotational motion. In this case, the slider is actually the piston of a car engine and it drives the crank and wheel. One can drag the slider to move the mechanism with a haptic device.

3. Student Experiments Procedure

The innovative course materials have been used in teaching in the Spring 2008 and Summer 2008 semesters. A pre-/posttest experiment with the undergraduate engineering students was conducted. We spent one lecture session on informing the students the lab contents and conducting the pre-assessment and data collection. After that, we scheduled the one-on-one lab instruction session with each student. The students were divided into a haptics training group and a control group to be taught with graphics animation only. At pre-test, all participants were presented with a battery of spatial reasoning and problem-solving ability tests. Each participant was randomly assigned to one of two groups: a) *Graphics group*: Participates in the pre- and post-test, but is taught *Dynamics* with graphics animation only; b) *Haptics group*: Participates in the pre- and post-test, but is taught *Dynamics* concepts combined with haptic-augmented animation. The effectiveness of the exemplary learning materials and tools is measured through analysis of survey and interview data (indirect measure) and student learning outcomes (direct measure).

Altogether 58 students took the pre-assessment. There are 22.5% female students. The minority is 29.3% of the whole batch. Altogether the percentage of the students from the underrepresented group is 37.9%. Due to the scheduling conflict, only 40 students were able to complete the lab sessions. Among these 40 students, 22.5% are female students, 37.5% are minority students and totally 45.0% are from the underrepresented group. These 40 students were split into two groups: 20 students in the graphics group and 20 students in the haptics group. The 40 students who completed all the study were paid for their participation.

4. Experiment Result Analysis

From the student experiments, many results are collected from the assessment materials. The following analyses include the cognitive domain and the affective domain of students' learning. The data analysis was conducted with MiniTab® statistics software.

The purpose of analyses on the *cognitive* domain is to find out whether students have learned from the lab, and whether haptics impacts their learning. The data used here are pre- and post-test assessment scores on all the 5 problems / concepts as discussed in Section 2. The student population under experiments is 40, which is enough for us to use the Central Limit Theory to assume normal distributions on the original data. Both groups of students entered the study with similar knowledge on all five cognitive items, as evidenced by lack of significant differences in their pre-test scores on all the five problems.

In order to assess if 'learning occurred' during the lab study in each group, paired t-tests (two-tailed, $\alpha = 0.05$) were used to determine whether the means of the post-tests were significantly different than those of the pre-tests on each problem in two treatment groups, i.e., haptics group and graphics group. It was found out that here were significant differences in the students' pre- and post-test scores on all problems in both groups.

The comparison conducted between the Graphics group and the Haptics group provides insight on whether haptics information provides additional help in achieving learning goals. First, we compared the learning improvement results between the two groups to see whether the Haptics Group achieved better learning improvement than the Graphics Group. To test for significant differences across two groups, gain scores on each problem were compared using two-sample independent t-tests (two-tailed, alpha = 0.05). The gain score is obtained by subtracting the pre-test scores from the post-test scores in each group[14]. The test tells us that insufficient evidence exists to reject the claim that the gain score means are equal. In other words, we cannot come to the conclusion that the gain scores of the Haptics Group are better than those of the Graphics Group. We thought that this could possibly be due to several reasons:

1) The graphics animation programs are designed so well that it is enough to convey sufficient information about the Dynamics concepts.
2) Past research suggests that when vision is available and adequate for a task, haptic exploration may not be invoked due to its relatively high processing cost[15]. With this in mind, it is suspected that students in this study learn concepts based primarily on visual information, even though a haptic channel is available.
3) The cognitive load on the students is another possible explanation. When students are presented with both visual and haptic information, on one hand, they may be able to quickly synthesize these information together to reinforce their understanding on Dynamics concepts; on the other hand, they may be too busy in assimilating the information, i.e., they are overloaded in taking information. The information processing ability varies in different people. This informs us that we need to judiciously design the human-machine user interface to reduce the cognitive load while maintaining sufficient information conveyance. Workload assessments method such as NASA-TLX may help reveal the more results.

The purpose of analyses on the *affective* domain is to find out the attitudinal changes of the students through the new learning materials. The pos-instruction Assessment of Instructional Module (AIM) questionnaire was analyzed for differences in students' attitudes toward the instructional program. This instrument contained Likert-scale (from 1-'strongly disagree' to 6-'strongly agree') items that asked the students to report their attitudes towards and interest level in the instructional program. The following AIM *Interest* items are common for Haptics Group vs. Graphics Group.

- Q1: I believe that the graphics and animation enhanced the material presented in the program.
- Q2: I am more interested in 'Dynamics' course after using the program.
- Q3: I believe that I have learned a lot more about these dynamics concepts by participating in this activity.
- Q4: The programs are different from the type of things we typically do in the class.
- Q5: I hope to use similar programs to help me learn other Engineering courses if applicable
- Q6: On a scale of 1 to 10, with 1 meaning 'not at all interesting' and a 10 meaning 'extremely interesting', how would you rate this program?

Q1~Q5 are questions with Likert-scale (from 1-'strongly disagree' to 6-'strongly agree'). Q6 is on a scale of 1 to 10. Since the data collected for these *Interest* items are ordinal, pair-t test is not suitable. Hence, a nonparametric test, the Mann-Whitney test (*a.k.a.* Wilcoxon Rank-Sum Test) is adopted for analysis, using MiniTab. The significant value α is selected as 0.05. According to the P-Value, there are no significant differences in Q1, Q4 and Q5, but there are significant differences in Q2, Q3 and Q6. Checking with the actual questions, we can conclude that students in both groups are positive about the instructional materials, while students in the haptics group are more positive towards the Dynamics course and new materials after the instruction. The responses to Q3 imply that the students in the Haptics group might actually learn more although the assessment in the Cognitive domain did not support this claim. A possible explanation is that we did not prepare appropriate assessment questions to check their learning results with the aid of a haptic interface, and thus their learning progress was not evaluated thoroughly.

5. Conclusions and Future Work

The development and analysis of the new 3D haptic-augmented learning tools provide us insights into the possible impact of the haptics in the engineering education. The assessment result shows that the innovative learning tools: 1) allow the students to interact with virtual objects with force feedback and better understand the abstract concepts by investigating the dynamics responses; 2) stimulate the students' learning interests in understanding the fundamental physics theories.

As the future work, we are currently upgrading the instructional program with a new user interface, by taking into the students' feedback. The next round of investigation will be teaching Dynamics with the new learning material in a lab session, instead of one-on-one teaching. Additionally, more judicious design of experiments and data analyses are necessary to reveal the potential of haptics in an Engineering classroom.

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