AC 2012-4332: ONLINE AUTOMATED INTERACTIVE UNDERGRADUATE PHYSICS COURSE AND LAB

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Online Automated Interactive Undergraduate Physics Course and Lab

Abstract

By fully automating all aspects of the learning experience for online courses, a large reduction of education costs can be achieved, while simultaneously matching or improving student performance as compared to human delivered online or traditional lectures. The main elements of an effective fully automated online course or lab are: fully automated content delivery using text-to-speech technology, highly visual course presentation using animated 2D and 3D illustrations that are synchronized with the course delivery, interactive 2D and 3D activities, and automated student assessments. A two semester undergraduate physics course that uses these elements to deliver a fully automated learning experience will be presented in this paper. The course can significantly decrease the cost of learning, while improving accessibility, quality, and uniformity of instruction. The course has a virtual reality physics lab with physics-based modeling of the relevant underlying principles and a variety of interactive physics experiments.

Introduction

Online courses are steadily gaining favor worldwide and in the US with almost one third of US higher education students taking at least one online course per year. The compound annual growth rate for online enrollment from fall 2002 to fall 2010 was 18.3%. This is almost 10 times the growth rate of 2.1% for overall higher education enrollment during the same time period¹. This indicates that in one or two decades online education will become the dominant form by which students receive instruction in higher learning institutions. Many institutions have adopted online education as a means to control the costs that are associated with a traditional classroom lecture. This includes teacher time, classroom space, educational equipment and supplies, and printed textbooks. Online courses also offer more convenient learning, since students can learn anywhere and at a pace that is most comfortable to them. Furthermore, although students of online courses can receive much more personalized instructions than students of traditional classroom lectures, in terms of the actual skills and knowledge that they learn, students of online courses can have much less variability than their traditional courses counterparts.

However, in a typical case of technique lagging behind technology², many online courses use the same methods to present their content as their traditional classroom counterparts, albeit on a computer screen. Hence many online courses use prerecorded videos of actual lectures, or web pages that mimic the pages of a traditional textbook. This does not make full use of the computer's capability to offer a truly compelling educational experience that includes 2D and 3D animations, interactive simulations, and advanced interfaces.

Automation in Online Learning

Courses can be classified based on how much of the content can be access online into traditional courses where no content is delivered online, web facilitated courses where up to 29% is delivered online, blended courses where up to 79% of the content is delivered online, and online courses where more than 80% of the content can be accessed on the internet¹. Online courses can be further categorized based on the level of automation of the content delivery, which is

inversely proportional to the level of involvement of a human instructor³. According to this classification, 0 to 29% of the content of instructor delivered online courses is automated. The instructor in this case typically lectures, answers student questions, and grades assignments and exams. This is currently the typical form that distance learning classes take. Partially automated courses are ones where 30 to 79% of the content is automated. The automated content typically includes lecturing and grading assignments and exams. Fully automated online courses have up to 100% content automation with little or no human instructor involvement in the learning process.

Instructor delivered online courses offer a cost advantage over their traditional counterparts due to the elimination of the need for a meeting space, and sometimes also the elimination of the textbook. However, in general instructor delivered courses require almost the same time commitment from the teacher. Since teacher salaries represent the main component of the cost of offering a course, the cost advantage of instructor delivered online courses over their traditional counterparts is small. Furthermore, instructor delivered online courses suffer from many of the disadvantages of regular classroom courses such as the lack of one-on-one attention from the teacher and students not being actively involved in the learning process.

For students taking about 10 classes per year, the average per class cost for tuition, fees, books and supplies at a community college is approximately \$400, while that value is \$900 at a typical university⁴. Given an estimated cost of between \$50 and \$100 for a fully automated online course, this represents about 12% to 25% of the cost of the cheaper community college option. This significant cost reduction can be achieved without a reduction in the quality of instruction. A small study of a fully automated high school machining course suggests that in terms of student comprehension, using only a well designed fully automated online course is as effective as traditional classroom/textbook/lab instruction⁵.

Content Delivery

The course content represents the information that the students should know after going through the course. In a fully automated online course, the content can be delivered in 3 methods:

1. *Written* content is delivered as web pages or pdf, doc or other file formats. This is the method employed by most online courses that are offered today.
2. *Pre-recorded* content can be in audio or video form. Although some students prefer listening or watching a video of a lecture to reading, this method of delivery offers the least flexibility in terms of making changes to the course. This is due to the fact that even to add a single word, an entire segment usually needs to be recorded anew.
3. *Text-to-speech* content delivery offers the most flexibility in terms of making changes to the course. This is due to the fact that any changes to the course can be typed directly into the text file of the content. This method also incorporates the main advantages of the previous two methods. Namely the efficient bandwidth use of written content and the voice delivery of pre-recorded content with almost the same voice quality.

The content delivered by fully automated online courses can also include graphical illustrations. The illustrations can be static or animated, 2D or 3D, and can be non-synchronized or

synchronized with content delivery. 2D snapshots of real or virtual 3D objects are still considered 2D illustrations since they can't be rotated, or zoomed. True 3D illustrations are usually displayed within a virtual environment that is navigated in first or third person. 3D models and 2D animations can be displayed in sync with the lecture delivery, or they can play independently of the lecture delivery.

Since it is more expensive and time consuming to develop 3D graphics as opposed to 2D graphics, course designers should not use 3D graphics indiscriminately for its novelty value. Rather, course designers should use 3D graphics only when they add educational value to the content. For example, in training applications on various machines, more effective and realistic training can be performed using a 3D virtual reality model of an actual machine⁶ (Figure 1). Furthermore, to teach concepts that are three dimensional in nature, it is better to use a 3D model that can be rotated and zoomed (Figure 2). Interactive course content can also greatly improve student engagement and comprehension. The interactive activities can be performed in a 2D (Figure 3) or 3D (Figure 1) setting.

Student Assessment

The student assessments can be performed in a 2D setting using multiple choice questions, drag and drop questions, and single or multi step numerical problems. In a 3D setting the student's performance of any training process can be tested and evaluated. For a fully automated course, the assembly of the assessment, its administration, the recording of the results, and the follow-up learning in case of a failure are done automatically. A significant portion of the teacher's time in traditional classrooms and in instructor delivered online classes is spent on the design, administration and grading of assessments. For this reason, teachers often limit the number of times students can be assessed on a given course section. This in turn limits the student's opportunity to improve their performance by using more than one learning and assessment cycle. Automated assessments, on the other hand, gives students an unlimited opportunity to improve their performance, and hence their grade. The system can also prevent students from moving to a subsequent course section until the student has demonstrated the required competency level in the current section. This approach can be used to ensure that students are fully proficient in every component topic of the course.

The Virtual Physics Lab

An online fully automated undergraduate university physics course with a virtual reality lab component was developed using the most effective of the approaches described above. The course, which is called the Virtual Physics Lab or VPL, uses text-to-speech technology to deliver its content in sync with text based delivery and 2D and 3D animations and interactive simulations (Figure 4). The VPL uses interactivity extensively both in 2D (Figures 3, 5) and 3D (Figure 4) formats. The virtual reality lab contains numerous interactive experiments including: sliding / rolling shapes on an inclined plane, sliding block on a flat plane (Figure 6), gravity drop tower, 2-mass pulley (Figure 4), spring mass system (Figure 6), pendulums (Figure 6), sliding and impact on a flat surface, rolling and impact on a flat surface, and vibration modes of a string. The virtual reality simulations use a physics based multibody dynamics engine to accurately model the momentum, friction, and impact forces experienced by the virtual objects⁷.

There are four main types of learning styles⁸. Visual learners learn through seeing, visualizing and drawing. Auditory learners learn through listening, discussions and talking. Read-write learners prefer text based input and output. Finally, kinesthetic learners learn through physically doing, manipulating and touching. People of a certain style type still learn using the other styles but they have a tendency to learn better if their style is stressed. The VPL is designed to address the needs of all four learning styles above.

1. Visual learners: They benefit from the VPL's engaging and eye-catching 2D and 3D multimedia elements.
2. Auditory learners: They are able to listen to the lecture being delivered by a natural sounding voice using the VPL's text-to-speech engine. The VPL allows the learners to choose between a male and a female voice, and to adjust the speed of the speech.
3. Read-write learners: They are able to read the course's content from the course's speech window (Figure 4) where the current sentence and word being spoken are highlighted in different colors. They could also turn off the voice delivery and virtual agent if they prefer to only read the content. The VPL also allows the playing of the course sentence by sentence by pressing on the next sentence button. This would allow read-write learners to view the graphical animations and highlights in sync with the course content read the content.
4. Kinesthetic learners: They benefit from the high level of interactivity that is available in the VPL. As explain previously, the VPL uses interactive 2D Adobe Flash simulations (Figure 5) and interactive 3D equipment and experiments (Figures 4, 6). The interactive simulations and equipment offer students the opportunity to experiment and learn by trial and error.

Conclusions

An advanced fully automated online tool for teaching undergraduate university physics was developed to enhance student learning both in terms of depth and speed, at a fraction of the cost of a traditional classroom lecture. The tool incorporates a high level of interactivity using 2D and 3D simulations to help keep students engaged in the learning process. The virtual reality lab that is incorporated into the tool allows students to conduct physics experiments that use an accurate multibody dynamics engine to model physical effects.

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Figure 1. Training on the setup, operation and programming of Computer Numeric Control (CNC) machines⁶.

Figure 2. A 2D (left) and 3D (right) illustration of the same phase diagram. Since phase diagrams are 3 dimensional by nature, it is more effective to view them and learn about them in a 3D virtual reality environment.

Figure 3. A 2D simulation of the ideal gas law.

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MEDIA

Derivation of the law governing the motion [619]

Derivation of the law governing the motion [619]

Postulate: $m a = F_R$ = the resultant force acting on body

$m_A a_A = -m_A g + F_T$ ①

$m_B a_B = -m_B g + F_T$ ②

$a_A = -a_B = a$

$m_A a = -m_A g + F_T$ ③

$m_B a = m_B g - F_T$ ④

③ + ④ $\Rightarrow (m_A + m_B) a = (m_B - m_A) g$

$a = \frac{(m_B - m_A)}{(m_A + m_B)} g = \frac{(2.5 - 2)}{(2 + 2.5)} \times 9.81 = 1.09 \text{ m/s}^2$

$a(t) = a_0 = 1.09 \text{ m/s}^2$

$v(t) = v(0) + \int_0^t a(t) dt = \int_0^t a_0 dt = a_0 t = 1.09 t$

$x(t) = x(0) + \int_0^t v(t) dt = \int_0^t a_0 t dt = \frac{1}{2} a_0 t^2 = 0.545 t^2$

SPEECH

forces acting on body B are: the weight of body B, which is pointing down in the negative y direction and the tension in the rope, which pulls body B upwards. . . Since the rope is continuous, and the

Figure 4. Segment from a fully automated undergraduate physics course. The virtual reality window on the right contains the virtual instructor and interactive virtual physics lab. The lecture window in the center is running an Adobe Flash animated slide. The speech window at the bottom contains a text version of the virtual tutor's computer generated speech. The outline window on the left contains a hierarchical clickable tree of the lecture's topics.

Figure 5. Examples of interactivity in 2D showing an experiment on neutral buoyancy (left) and a comparison of a trochoid curve with a sinusoid curve at different values of the radius of the point that is tracing the trochoid.

Figure 6. Examples of interactive 3D simulations: block on a flat plane (top left), mass spring system (top right), pendulums (bottom).