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Simulation and Haptic Devices in Engineering Education

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Introduction

Knowledge acquisition is especially meaningful when theoretical concepts are applied in real or quasi-real contexts to consolidate learning. However, this is not always possible due to the nature of the concepts to be taught or because of economic, ethical or social reasons. In those cases, simulation environments can be excellent learning tools because they can replicate real contexts or even provide training situations that occur in very specific circumstances. Naturally, the closer these systems model reality, the more effective will be the learning process.

The use of Virtual Reality (VR) environments for learning has been a research matter for the past few years. When these environments are merged with haptic devices - a tactile sensory interface between a person and a computer - highly realistic environments are created, where different experiments can be implemented.

This article describes a methodology to integrate these environments in education, providing new and innovative learning methods. Examples of the use of these simulation processes are described. One relates to the study of aerodynamic forces with resource to a low-cost haptic device. Students use an application that represents the magnitude of the four aerodynamic forces and manipulate data on speed, angle of attack and status of the airplane, therefore changing the plane position and flight (take-up, landing, cruising, etc.). The resultant of the forces is "felt" by the user through the haptic mechanism.

A validation test study was conducted and students were faced with situations that they had to replicate in the simulator. After using the simulator they had to answer a few questions about their experience. It was clear that, by being immersed in the simulation environment, students readily establish the connection between the theoretical concepts and the practice.

Haptic Devices

No matter how powerful or elegant is an underlying technology to multimedia computing, it is the user interface that determines how the system will be used [1]. Furthermore, in many situations, it is this interface that determines the effectiveness and user satisfaction with the application. Grilo et al. argue that VR defines scenarios where the user interacts and navigates through multi-sensory (images, sounds, touch, etc) channels in a three-dimensional computer generated immersive environment [2].

To amplify the sense of presence or immersion in a virtual environment it is necessary for sensory perception to be performed in real time with the help of interactive devices that guarantee adequate input and response (feedback).

An important component of multi-sensory communication is the sense of touch. It is known that the sense of touch is inevitable to understand the real world [3] and haptic systems provide that possibility.

The word haptic is an adjective that means "relative to the touch, touch". Comes from the merger of the Greek word “Haptikos”, and “ón". It now denominates the science of touch and the study and simulation of pressure, texture, vibration and other meanings expressed through touch.

Haptic systems are used mainly in the area of VR and are gaining wide acceptance, adding the sense of touch to vision and audio. Different types of haptic devices provide interaction with the hand, arm or even the whole body. Current haptic systems are used in simulators, games, research, medicine, literature, robotics, art and design. A simple example of the use of haptic devices in the field of games is the wheel for driving simulators that are programmed to enable the driver "feel" the road (bumps, trepidation, etc…).

In the medical field, various haptic interfaces for medical simulations have been instrumental in the training of invasive procedures and the establishment of surgeries using remote tele-operators. In the future, experienced surgeons may work from a central workstation, performing operations remotely. A particular advantage of this type of work is that a surgeon can perform many more operations of the same type thus becoming more effective.

The purpose of this technology is then to mimic reality in order to amplify the feeling of truth to the user.

With VR and haptic environments, the user explores with all its senses, especially with the natural three-dimensional body movements, to view, manipulate and explore data in real time applications. The great advantage of this type of interface is that the intuitive knowledge of the user's physical world becomes beneficial to dominate the virtual world.

VR is not only a replica of real worlds, but it allows creating imaginary environments with elements with meaning for the subject of study. For instance, if students are learning about gravitational theory it is possible to create virtual fake planets, with imaginary gravitational conditions.

Although there is already equipment capable of enhanced interaction there is still a lack of popularity derived from its high cost and lack of standardization of access [4]. But, it is clear that as computers progress, the greater is the support to the sense pallet of mankind. It is likely that the sense of touch is the next sense to play an important role in this evolution [5].

And finally we are reaching a stage where the cost of haptic devices is becoming reasonable and allowing its incorporation in the education world.

Learning Methodology

Using the computer in teaching/learning, for instance through simulators, makes possible the practical study of various subjects that are difficult or impossible to experience in real life. [6] argues that technology provides a new charm to school, to open their walls and allow that students and teachers to share their knowledge.

According to [7], at present the tendency is to accept and implement paradigms where the focus is the student and the interaction between teacher and students is performed with the help of knowledge systems. But, in fact, the adaptation to new methodologies of teaching and learning are still burdened with the traditional model of education. Pereira declared that the teacher had to know that "teaching is not only to transfer knowledge but to create opportunities for their production or construction. The traditional process of knowledge building is based only on the cognitive aspects in the theory and practice transforming the student in a passive agent. In this type of education, there is neither incentive nor space to promote the student [8]. So, there is still the need to prepare formal education for the use of these new generations of learning tools, but also to develop them for learner autonomy, cooperation, creativity and critical analysis. Learning with these tools should emphasize visualizing, hearing, feeling, experimenting and interpreting so that there is an effective construction of knowledge [9].

Haptic systems enable this incentive through a new type of interaction with the computer, making a dive into a virtual 3D environment with a sense of higher reality, absent in conventional VR systems. The advances and capabilities of this technology launch a new way of learning. It allows simulating the sensation of touch, strength, weight, shapes and even textures, so the students can perceive and understand physical concepts in a practical and realistic way. The use of this feature is innovative and creative in the design and transmission of knowledge and in fostering motivation and interest of students.

During the last decade there has been a rapid growth in the number and types of haptic devices and virtual reality applications. However, according to, the existing research in terms of student learning with these devices, particularly in science education, is still sparse.

It can be concluded, by the lack of information available, that the haptic technology is not yet included as an educational tool and according to, most of these existing applications focused on surgery, dentistry and navigation areas. Certainly this technology has yet to assert itself as an emerging technology and establish itself as a mechanism to support learning.

Examples and Results

As an example of the application of the learning methodology with/through haptic VR environments, we developed a simulation for aerodynamics laws. The phenomenon under study is the movement of air and the consequent behavior it produces in certain objects, such as the wings of an airplane. This behavior and the corresponding forces are essentially reproduced in the haptic device. The visual information in the existing simulation assists students to associate the values and directions of the forces that exist in reality.

Although the main purpose is learning by the practical application of the aerodynamics law concepts, the simulation will also be beneficial for a teacher to transmit the related contents.

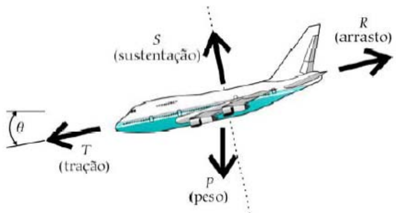

Fig. 1. Aerodynamic Forces in a plane

If we consider a two dimensional space, in a certain moment the sum of the forces must be 0, therefore,

$$\sum Fx = 0 \Leftrightarrow T - P * Sen\,\theta - R = 0\,, \quad (1)$$

$$\sum Fy = 0 \Leftrightarrow S - P * Cos\,\theta = 0 \Leftrightarrow S = P * Cos\,\theta, \quad (2)$$

The users feel the effects of simulated touch through the Novint Falcon haptic device. At the moment this is the best investment because it is an award-winning device, capable of exercising more than 1 kg of force and with a quite affordable price.

Fig. 2. Novint Falcon

Furthermore, the company producer delivers several applications and an SDK for development of new applications or modifications of existing ones. Programming is done through Python and X3D using the H3D API.

A wind tunnel was the scenario depicted in the simulation developed for the study of aerodynamic phenomena of the flight of an airplane.

The interface of the simulator shows a plane P-38 Lightning (second World War), a scheme to represent the magnitude of the four aerodynamic forces (meter forces similar to that seen in Formula 1 racing which shows the G-forces experienced by the pilot) and data on speed, angle of attack and status of the airplane, ie tells if the airplane is on the take-off, climbing, cruise flight, etc.

Fig. 3. Simulation environment

The resultant of forces is "felt" by the user through the haptic mechanism. The user can understand the whole process of starting the plane, takeoff, flight and loss of ability to remain in flight. The user controls the increase and decrease in speed of the plane and this variation is obviously directly related to the increase and decrease in air velocity. Similarly the user can vary the angle of attack from -15 degrees to 15 degrees. Outside this range the plane would go into stall. Thus the student can, by changing speed and angle of attack, experiment the effects of air going through the wings of the plane by the forces applied to same.

The validation of the simulation was conducted with two classes of the first year of the Computer Engineering degree from ISEP (Instituto Superior de Engenharia do Porto). The test process was performed as follows:

1) Demonstration of the haptic device using a set of tutorials;

2) Explanation of some concepts necessary for understanding simulation of the aerodynamic forces;

3) Clarification of the aerodynamics simulator interface;

4) Test activities for students to implement and answer a series of questions about the behavior of the aircraft and forces exercised;

5) Questionnaire about the perception that the students had about the simulation, haptic systems and their use in teaching.

The proposed questions for the exam simulator were:

1) Why is it that, when speed is zero, the resultant of the forces points down?;

Response: Since there is no support at zero speed, there is only gravity;

2) Why is it that the plane takes off only from a speed of 150 km/h (what happens in the scheme of forces)?;

Answer: Only after this speed there is enough support to overcome the force of gravity;

3) With the angle of attack of 0 degrees, the plane accelerates. Note that the plane rises slightly even without attack angle. Why?;

Answer: Because of the shape of the wing. Its asymmetrical shape between upper surface of the wing with the underside of the wing results in a slight elevation of the plane.

4) When the plane slows down the resultant of forces points backwards and down. Why is this happening?

Answer: A decrease in speed decreases the strength of momentum, so the friction force (wind) becomes higher. At the same time reducing the impulse originates a reduction of the support, which becomes smaller than the weight and leads to the descent of the plane.

5) Why is it that when the plane slows down to speeds below 150 Km/h the resultant force points down and the angle of attack decreases?

Answer: Because the plane enters into loss. You cannot keep flight in these conditions. The resultant of forces points down and plane decreases the angle of attack.

To assess the perception of the students in the relation to the interest and use of the haptic simulators in this and other aspects of Engineering, a set of questionnaires was handed to the involved students. The questions were the following:

a) The application is intuitive? 69% of the students answered that the application was highly intuitive. Only 6% didn’t find it intuitive;

b) They think that this application offers a better understanding of the physics of flight? All the students replied positively;

c) They feel that the more practical style of haptic systems applied to education gives greater motivation to learn? All the students replied positively;

d) Do you consider that haptic systems should be applied to other disciplines? Again, all the students replied positively.

Conclusions

The system has been applied to first year Engineering students in a case study experiment to validate the learning methodology. In the end their knowledge was tested and their perception on the relevance and interest of the system was evaluated. Results show that physics understanding was greatly enhanced and that students motivation for learning, even theoretical aspects and concepts, was increased.

In relation to the practical way of learning using haptic technology it is clear that it raised the interest and motivation of the students. It is also clear, from the students’ motivation, the analysis of the results and considering the current cost of the purchase of equipment and software and the development of new applications, that we've reached a point of equilibrium. It is already a cost-effective approach to reduce the number of dropouts and failure. All students have found a good or excellent idea to use haptic systems in other disciplines, so it appears that there sufficient grounds to say that an investment is warranted in this area.

The study on new ways of teaching using new technologies revealed that the teacher continues to be necessary before the theoretical explanation of the practice and clarify any doubt. The prototype test carried out with the two groups unveiled this need to have someone guiding students in practical exercises and ensuring that the student really understood the issues.

The growth in the use of devices such as haptic input device computer together with the reduction of their prices, thus enables a ease of obtaining this kind of apparatus and consequently to increased production of a greater number of applications that are applied to education or other purposes.

You could say that technology haptic sensory systems will spread as a important means of interaction between man and machine and it will lead to a major evolution of such systems.

In the future the simulation of aerodynamic forces may undergo several improvements in a graphical user interface and operation, as long room for further development in relation to physical forces.

As a consequence new simulation contexts are being prepared, for the demonstration and study of electromagnetical and friction forces.

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This article describes one methodology to integrate haptic devices in education, providing a new and innovative learning method. Examples of the methodology are given: the study of flight aerodynamics with resource to a low-cost haptic device - a tactile sensory interface between a person and a computer. A wind tunnel is the scenario depicted in the simulation and the interface shows a P-38 Lightning plane (from World War II). Students see a scheme that represents the magnitude of the four aerodynamic forces and data on speed, angle of attack and status of the airplane, which tells if the airplane is on the take-up, and so on. The resultant of the forces is "felt" by the user through the haptic mechanism. The system has been applied to first year Engineering students in a case study experiment to validate the learning methodology. In the end their knowledge was tested and their perception on the relevance and interest of the system was evaluated. Results show that physics understanding was greatly enhanced and that students motivation for learning, even theoretical aspects and concepts, was increased. Ill. 3, bibl. 9 (in English; abstracts in English, Russian and Lithuanian).

Д. Лопес, С. С. Ваз де Царвалхо. Применения различных чуствительных стимуляторов в учебном процессе инженерного профиля // Электроника и электротехника. – Каунас: Технология, 2010. – № 6(102). – С. 159–162.

Описывается новый метод обучения инженеров, основанный на биологической связи человека и компьютера. Эксперимент проведен со студентами при изучении полета самолетов, когда сила подъема и спуска устанавливается чувствительными приборами. Установлено, что такой метод значительно углубляет физическое познание студентов и их желание учиться. Ил. 3, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Lopes, C. Vaz de Carvalho. Simuliatorių ir lietimui jautrių prietaisų taikymas inžinerinio mokymo procese // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 6(102). – P. 159–162.

Pristatomas imitatorių ir lietimui jautrių prietaisų taikymas inžinerinio mokymo procese. Tai naujas, inovatyvus mokymo metodas. Pateikta metodologijos pavyzdžių: skrydžių aerodinamikos studija su lietimui jautria žmogaus ir kompiuterio tarpusavio sąsaja. Aprašytas vėjo tunelis ir lėktuvas P-38 Lightning. Studentai gauna įvairių duomenų, iš kurių matyti, ar lėktuvas kyla, ar leidžiasi ir pan. Jėgų atstojamoji jaučiama per lietimui jautrų prietaisą. Studentų įgytos žinios buvo tikrinamos ir susistemintos, įvertinta, kaip jie suvokia sistemos aktualumą. Nustatyta, kad tai labai pagerino fizikinių žinių suvokimą, studentų mokymosi motyvaciją. Il. 3, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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