DEVELOPMENT OF AUGMENTED REALITY LABORATORY EXPERIMENTS IN BIOLOGY CLASSES

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Abstract

Augmented reality can be described as a method that combines the real environment and the virtual data in real time. In the paper a classroom example of the exercise Mealworm respiration is presented, where the augmented reality was used as support in the computer-based biology laboratory. In the exercise the students can focus directly on the experiment itself because the real-time data from data-loggers are presented as the virtual sensors next to the experiment. The aim of the work was to develop virtual sensors that could be later used in virtual biology laboratory.

Introduction

Augmented reality (AR) is a technology that uses the user's environment as a background for the virtual (synthetics) objects. Virtual objects and their real background are blended to create a composite view in which the user feels that the virtual objects are present in a real environment (Behzadan, Timm, & Kamat, 2008). AR was developed from its predecessor virtual reality (VR). When comparing AR with VR, the main advantage of it is that the user is able to see the real world around him (Azuma, 1997; Martin-Gutierrez, Saorin, Contero, Alcaniz, Perez-Lopez, & Ortega, 2010).

In the last decade numerous studies were performed dealing with the usage of AR in different disciplines. After successful use in the military (Azuma, 1997), medicine (Azuma, 1997; Bajura, Fuchs, & Ohbuchi, 1992; Klein et al., 2009) and industry (Anastassova & Burkhardt, 2009; Behzadan et al., 2008), it became a useful teaching tool in the classrooms (Billinghurst, Kata, & Poupyrev, 2001; Chen and Wang, 2008; Gelenbe, Hussain, & Kaptan, 2005; Kerawalla, Luckin, Seljeflot, & Wollard, 2006). One of the basic attempts of using AR in the field of education is the MagicBook, where AR support is implemented in a traditional book (Billinghurst et al., 2001). While there are many studies dealing with medical education (Klein et al., 2009; Porro, Schenone, Fato, Raposio, Molinari, & Beltrame, 2005), there can be found only a few examples of AR dealing with biology — for example: molecular models (Gillet, Sanner, Stoffler, & Olson, 2005). Despite the popularity, the virtual and remote biology laboratory experiments are not realized as we would like them to be.

One of the possibilities for not using virtual technologies in biology is the high expenses that occur with development and maintaining of the technologies (Kaufmann & Schmalstieg, 2003). It is hard to expect that schools will purchase them, especially if the students could still learn without them in a traditional way. But the numbers are not always realistic. The consciousness that the equipment once bought can be used over and over again (for example even for more than one school subject) should diminish the actual price. The next reason is that biology classes are generally connected with the nature and teachers do not want to use simulations instead of using real “things” (Puhek & Šorgo, 2009). But with adding virtual objects to the real world (AR), a natural mechanism for manipulation and exploration is used (Gillet et al., 2005). While we can illustrate virtual objects that are harmless, we can significantly reduce costs and hazards (Azuma, 1997; Gelenbe et al., 2005). With these characteristics the world of AR could be used as a training ground in realistic environments, such as laboratories or other potentially dangerous places. There is no need to purchase special instruments or other equipment, therefore the budget is affordable (Porro et al., 2005) and the impact on the traditional work is not changed. The information converted by the virtual objects helps the user to perform real-world tasks. Last but not the least advantage of using AR is the attraction that is gained through application which is used in everyday situations. Many learning games have been made with it, which enable students to learn through playing a game (Pan, Cheok, Yan, Zhu, & Shi, 2006).

In the paper a combination of the learning environment in laboratory and the virtual objects, supplied by the augmented reality (AR), are described. With knowledge that Slovenian students prefer the method of computer-based laboratory work, especially if active work is included (Špernjak and Šorgo, 2009), this method was taken as the grounding. In AR we found a potential to present measurement data from the computer display next to the measuring equipment. That made our exercise friendlier for usage and at the same time, with the use of a new technology, even more attractive for the students. The main reason for using AR was the fact that it is hard at the same time to concentrate on the results that are displayed on the monitor and to follow the course of experiment with sensors. One simple computer-based biology laboratory exercise (the respiration of mealworms) was selected and virtual sensors were added. With that the user is able to see virtual data results next to the real sensors and does not need focus on the display.

Background of the Mealworm Respiration Experiment

In the biology laboratory we can differentiate the real and the virtual work. The virtual work is presented through simulations and animations, where the computer or other audio-video equipment plays the key role and enables different virtual environments. On the other hand, the real work is divided on the classical and on the computer supported laboratory work (Kocijančič & O'Sullivan, 2004). Classical experiments and computer-supported experiments are performed through active work with real sensors and other laboratory equipment. Based on different parameters we decided to divide computer-supported work on traditional and AR-supported computer laboratory work. For both "real" and "virtual" laboratory advances and obstacles are reported (Šorgo, 2007). For example students are more active when they are learning through "real" laboratory work (they develop hand skills), but that can sometimes be dangerous. In the virtual laboratory we can simulate various experiments without any risk (radioactive pollution, dangerous chemicals), but students are passive and after some time they can even get bored (Špernjak & Šorgo, 2009).

The classical experiment for measuring the respiration caused by live organisms was usually performed with the help of indicators such as phenol red or bromothymol blue (Drašler, 1999). In the process of respiration every live organism produces CO_2 (carbon dioxide). CO_2 has the property of transforming into carbonic acid when it is dissolved into water. Phenol red is a well known pH indicator denoted through its typical red colour. It changes its colour when exposed to acid. When it contacts carbonic acid, it turns yellow. In the exercise students prove that living organisms produce CO_2 because the indicator colour is changed only in the test tubes with living organisms. Bromothymol blue is commonly used to demonstrate that the more muscles are used the greater the CO_2 output is. In that exercise students need to perform different physical exercises (for example, push ups); after doing so they have to exhale through the tube into indicator. Again, when CO_2 is mixed with water, carbonic acid is produced. When the indicator is exposed to carbonic acid, it changes its colour.

For our computer supported biology exercises we used the Vernier's data loggers. One of the reasons for the decision to use these data loggers was the wide use of this device in Slovenian schools (Šorgo, 2007), financed by the Slovenian government. Vernier's data loggers were purposed to help biology, chemistry and physics teachers. On the other hand, Vernier's data loggers are easy to handle and maintain. The system consist of different basic sensors (for temperature, O_2 and CO_2, gas pressure, pH, conductivity, force, etc.) and other additional equipment (gas chambers, blood pressure sensors, chromatographs, motion detectors, colorimeters, GPS units, DNA bio-imaging systems, etc.).

With the data loggers numerous experiments can be carried out. The quantity of experiments depends on the imagination of the teacher. At the same time those sensors can be used for preparing of different school subjects. From that perspective, buying is reasonable, because they can be used by biology, chemistry and physics teachers. At the same time it makes the class interdisciplinary. Students can learn important lesson on how things are combined in nature.

Methodology

The main aim of the work was to integrate AR into computer-supported biology exercises. With the purpose to develop an exercise that can be expanded later and used in the classrooms without any additional costs, open source software was used. Generally, the exercise is a combination of the work in biology laboratory and the computer-based work. For laboratory equipment the Vernier's data loggers with their software LoggerPro were chosen. LoggerPro is software that provides the user with the data from sensors. Firstly, the computer work was used to make virtual 3-D objects and after that to fit them to the AR. Because the purpose was to test how AR combines with the computer-based laboratory work, a biology laboratory environment with a small number of sensors was chosen.

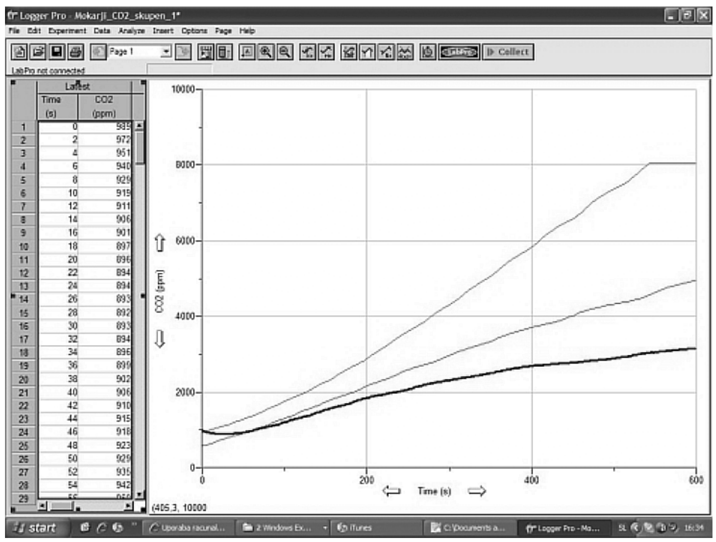
Design of Laboratory Environment

In the exercise Mealworm Respiration students study the influence of temperature on mealworm respiration. They measure the volume of carbon dioxide and the temperature. The main aim of the exercise was to determine whether the rise in the temperature increases the respiration of mealworms and also what happens if the temperature drops. Mealworm larvae (Tenebrio molitor) in mass of 100 grams were used for this exercise. We chose these larvae because they are common in Slovenian schools. They are not demanding to breed and can be used for many different class activities (for example, when students are studying the characteristics of the living organisms and at the same time as food for lizards and spiders). The mealworms were put into a Vernier's plastic chamber where the carbon dioxide measuring sensor was installed. If there is no original plastic chamber available, a homemade version can be built out of a plastic bottle. When building our own chamber it is important that the sensor fits into it, because otherwise the measurements would not be real. In the case described, the sensor is going to detect the value of CO_2 from the laboratory and not from the chamber as they're supposed to. The chamber is then put into the water bath in a beaker. We measured differences that occurred as a consequence of different temperatures of the water. For cooling the water we used ice and for warming it up we decided for the water heater. For the control a water bath with water of room temperature was used. Between single measurements we waited several minutes, so that the mealworms calmed down. The measurements were carried out in three temperature ranges:

- water cooled with ice (4–7 °C)
- water room at temperature (approximately 23 °C)
- warmed water (35–38 °C).

During the classical experiment we could clearly define that the mealworms were more active when the temperature was higher, and that they were less active when the temperature dropped. The mealworms created more CO_2 when it was warmer than when the temperature was lower. This can be observed in Figure 1, which presents the output file of LoggerPro. The graphs for different temperature ranges can be clearly distinguished from each other.

Figure 1: Example of output data, provided by Verier's software LoggerPro during Mealworm respirations computer-supported experiment.



Design of Computer-based Environment

Firstly, rough designs of what would be the ideal way to present the temperature and volume of carbon dioxide were made. The purpose was to use the 3-D objects, which are attractive and educational at the same time. In the first part of their study Gillet et al. (2005) showed that molecular biology students found AR models engaging and instructive. In our experiment we decided on a virtual thermometer and a gas tank.

The next step included the search for an adequate 3-D modelling tool. The most appropriate tool had to be free, easy to handle, and be able to be exported into VRML (virtual reality modelling language). Blender (http://www.blender.org) was the software that fitted all the requirements. This is a free open source suite, which can be used on different operation systems (Windows, Linux, Mac OS, Solaris, and Irix). It also enables the exporting of objects in different formats, also to VRML. When working with Blender the user designs the virtual objects from a basic form. Both the thermometer and the gas tank were created from the cylinder as a basic form. Blender enables the usage of different colours, shading effects and animations. The user can even control the settings of the light.

The final step was to design the AR environment which presents the data from sensors (data gained with the software LoggerPro) in real time in the form of virtual objects. We used ARToolKit, which represents the heart of our AR-supported biology exercise. To prepare our application for supporting AR with ARToolKit we had to master the C++ programming language. The main problem while developing the "linking" application was the transmission of the gained measurements. The sensors defined the measurements, but their instant implementation to the AR environment presented the main difficulty of the study. Virtual objects in the experiments can be marked as accurate only when data is updated. The most important functions when programming with ARToolKit are the following: main, init, mainLoop, draw, and cleanup (ARToolKit, 2011). In the main function, we run the init function that initializes the video capture and searches for the markers and camera parameters. The next important function is mainLoop where the markers are recognized and the position of them is calculated regarding the position of the video camera and the marker. The function mainLoop is repeated for every frame. Those markers are the base for the projection of the virtual objects. The virtual objects are drawn with help of the draw function, which runs from mainLoop function. Finally, we close the video capture in our programme with the cleanup function.

Didactical Design of Augmented Reality Experiments

In the natural sciences reading and communication in general are very important. While sometimes ideas can be discussed and proven in a classroom, this is not always the case. Numerous definitions and conclusions have to be proven in the laboratories (Drašler, 1999). When doing so, all students have to be able to participate in the process equally.

From the didactical point of view, the laboratory work is of great importance for the students. The lack of variety in the lectures is changed through a practical input. A genuine relationship between the teacher and the students is developed because the teacher is not longer only in the role of the lecturer but becomes a consulter when performing laboratory experiments. Consequently, the communication between teachers and students is increased. A study shows that students would like more laboratory work incorporated into the schooling system (Špernjak & Šorgo, 2009). The laboratory work gives the students two different perspectives on a problem. In the first, students are provided with a theoretical basis, which motivates students to apply gained knowledge to the praxis. The second approach does not give them the theory as a basis. Students develop conclusions from the practical work performed and are encouraged to give their own findings that lead them to the theory (Domin, 1999). One of numerous positive effects of non-theoretical teaching is the variegation of the teaching process and the opportunity given to the students to be included.

Results and Discussion

Augmented reality defines the laboratory work at the next level. When comparing our work with findings of previous studies we found that one of the first attempts of integrating AR into education was a book concept (Billinghurst et al., 2001; Martin-Gutierrez et al., 2010). This concept was brought to our attention because it represents an additional information system (like a pop-up window with additional explanation). Although the system was effective, we wanted to create something more dynamic for the laboratory. With the dynamic real-time capturing application we came across another difficulty, presented through developing a new application for connecting the sensors' software and show data in AR mode.

The AR-supported biology laboratory exercise consists from a "self-running" application that is added to the Vernier's data loggers. This application enables real-time data transfer from sensors to the virtual presentation on the display. Firstly, the user needs to set up the sensors and interface for data collection. Two markers (black squares) need to be placed on the area where we want the virtual objects to appear. A marker has to be copied on a paper; the results are optimal, if the paper with marker is than glued to a hard surface (pasteboard, plastic) which prevents the marker from folding. If the marker cannot be printed, we can still use the old-fashioned option and draw it. However, in this case the camera can have some difficulties detecting the marker because drawn edges are usually not as straight as printed ones and consequently can be difficult to detect.

After the system is prepared, the AR presenting application can be launched. This application will enable the user to see virtual objects which will change in dependence of real measurements from sensors. The information is shown in new dimensions, which can also improve its quality (Haniff, 1999). The 3-D virtual thermometer and gas tank enable students to get another perspective of measurements than was usual in the past (only from the graph), which can also have a measurable and positive impact on students' spatial ability (Martin-Gutierrez et al., 2010). Because virtual objects cannot be seen with the naked eye, the experiment needs to be captured with video camera. The expenses encouraged us to include affordable equipment for the biology laboratory exercises such as a low-cost USB camera and open source software because at the same time we wanted to test the quality of the equipment. We supposed that this type of cameras was more widely used in secondary school laboratories because, as Kaufmann et al. (2003) point out, it is not realistic to expect that a school can provide extremely expensive tracking systems, head mounted displays, and stereoscopic video projections. More efficient (and consequently more expensive) cameras can just work better, because the detection of marker is more accurate. If the camera is missing or is not installed successfully, the AR application is not going to work and informs the user about the problem.

The aim of the application is to search for the markers. We used one marker for each of the virtual objects: one for the thermometer and one for the CO_2 gas tank.

If a marker is detected, software calculates its position and the position of the camera. Consequently, a virtual thermometer or a virtual gas tank is projected on that area. It is possible to move virtual object when moving the marker. This way more natural mechanisms for manipulation and exploration are provided (Gillet et al., 2005). If everything is prepared sucessfuly, an AR-supported experiment is presented on the display (Figure 2). Despite high costs, a more optimal choice would be to use a head mounted display (HMD). This device "replaces" the need for a computer display and enables the user a more realistic experience of the AR experiment. For the experiment to work, one of the first conditions to be fulfilled is the right position of the camera regarding the marker. If the camera cannot detect the marker, the virtual object cannot be seen (left marker on the Figure 2). At this stage the quality of the equipment is crucial. A low-cost camera has a weaker ability to detect the objects and can therefore miss the inputs.

Figure 2: The main set-up of biology exercise Mealworm respiration, supported by augmented reality.

In terms of usability Anastassova (2009) defines the future AR system as easy to use, compatible with the technologies used already during training, and with minimal cost. Although some difficulties such as lower quality of video and light are present when using low cost equipment can occur, the introduction of AR-supported laboratory exercises in the classrooms would have an extremely positive effect on the students' perception.

Conclusion and Future Plans

In this paper a classroom example of an exercise using augmented reality to support in a computer-based biology laboratory is presented. In general teachers have difficulties when accepting new technologies, especially if they are not unavoidably necessary for the teaching; therefore we developed a system which uses AR as a support to data loggers that they already possess.

The aim of the work was to develop virtual sensors that could be later used in virtual biology laboratory or even with the outdoor activities. In the exercise Mealworm Respiration students study the influence of the temperature on the mealworm respiration. They measure the volume of carbon dioxide and the temperature. Compared to the computer-supported exercise, where only data loggers are used, in the augmented-supported exercise the students can focus directly on the experiment itself, because the real-time data from data-loggers are presented as the virtual sensors next to the experiment. Regarding the findings of previous work, it is easier to concentrate only on one component. From the pedagogical point of view the proposed system shows greater activity of the students when they are included in the learning process. For example students are practicing to read the values from the virtual thermometer and not only from the graph on the screen.

As a proposal of an AR supported exercise Mealworm Respiration was developed. It should serve as the basis of a virtual laboratory, which would be acceptable for biology classes. AR blends virtual equipment into the real environment. The main perspective of the work was to develop an application that calculates the position of the marker and projects virtual thermometer or a virtual gas tank on an area where a marker is detected. To optimize the exercise an evaluation in a classroom should be carried out, where users' suggestions and opinions could be taken into consideration. With that kind of information more involved work and mending of weaknesses could be performed. In the future our aim is to create more exercises that would introduce different themes and to develop 'lite' versions of the application that could be used outdoors. More sophisticated ways of supplying the user with information are possible (for example, time can be presented as sand clock). All virtual components can be later combined in a virtual graph.

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