Simulation Teaching in 3D Augmented Reality Environment

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***Abstract*—Traditional 3D virtual environments give people an isolated feeling in their interactive experience. This paper proposes a simulation instruction mode based on 3D Augmented Reality (AR) environments which can improve interactive experience. The camera detects the presetting markers which will later generate 3D virtual objects and shoots teachers' and students' real experimental operations at the same time, interposing the virtual objects on the real scene to produce a blended environment. With that technology, we construct both the local AR-based environments and the distant AR-based environments and devise several simulation instruction cases, such as Newton's First Law of Motion, Newton's Second Law of Motion, Simple Pendulum and Ants Meeting Algorithm, etc. According to the experimental analysis of students' learning interests and learning results, we conclude that in an AR-based learning environment, students adopt a natural interactive method and enjoy the same experience as in real environments due to the abandonment of mouse and keyboard devices. Furthermore, that blended AR-based learning environment is able to interpose objects which are inaccessible in real life due to limitation of expenses and safety or some other factors on the real scene, presenting an innovative and fascinating learning mode which eliminates the isolated feeling in learning.**

Keywords-Augmented reality; simulation; interaction

I. INTRODUCTION

Traditional learning is considered to be a boring process, whereas the emergence of simulation technologies totally revolutionized people's ideas about learning. Virtual learning environments have brought completely new experience for learners.

According to Chittaro and Ranon's research, compared with traditional learning method, virtual learning environments help to reduce learners' cognitive load during their learning process [1]. In another research conducted by James Clarence Rosser, surgeons who play simulation-videogames for at least 3 hours per week keep a record of 27% higher speed and 37% fewer mistakes when performing operations than surgeons who have never participated in such games [2]. Numbers of universities have adopted Second Life as a platform for virtual classes, which provides education opportunities for a larger range of people and to some extent narrows the "Digital Divide" by offering help to students who do not have access to favorable school education. Further, as a branch of Virtual Reality (VR), Augmented Reality (AR) successfully blends the virtual world and real world, which brings about richer immersive experience than ordinary virtual reality technologies.

The difference between Augmented Reality and Virtual Reality lies in that Virtual Reality constructs a complete virtual world. When users are immersed in a virtual world, they are not conscious of the real world around them. Unlike Virtual Reality, Augmented Reality blends the scene of virtual objects with the real world and presents them to users at the same time. Thanks to which users can operate virtual objects interposed on the real scene to acquire the most authentic user experience.AR environments provide users with a seamless interface to connect the real world and the virtual world,

In the AR-based learning environment, Augmented Reality helps to vividly demonstrate both the real world which is not accessible to learners and the micro worlds which only exist in learners' imagination by using 3D animation. In this way, it will be easier for learners to observe closely into the matters in these worlds and explore the essence and disciplines behind them. Moreover, Augmented Reality make information reification, which means information is blended into the real surroundings of users. It helps to remove the gulf between learners and the information to be acquired, making learning activities as natural as the normal interaction between students and teachers.[3]

II. RELATED WORKS

Kaufmann realizes interactions between teachers and students with the help of Augmented Reality. The system can present the structure of simple points, lines and sides and possesses the function of Boolean calculation. In that system, teachers can easily illustrate the transformation of geometrics and their relations in space. It shows that students get a better understanding of complicated spatial concepts in the 3D environment which blends reality and virtuality [4]. Dünser and Horneker adopt fable stories as contents, in addition with 3D roles, sounds and interaction tools to observe how children aged 5-7 interact and conduct cooperative learning with the help of Augmented Reality. The children participated in the experiment are required to use interaction

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tools attached with markers to read the stories and finish several relative small tasks. The research indicates that Augmented Reality draws children's attention and makes them willing to keep on trying to finish the tasks [5]. Mulloni devised a game called "Bull and UFO". It is a group rivalry game which utilizes the Bluetooth settings on mobile devices and cards with markers on them [6]. Researchers from Vienna Institute of Technology demonstrate the application of Augmented Reality in the teaching of mechanics [7]. It utilizes a physics engine developed for computer games to simulate the physics experiments in the arena of mechanics at real time. Students are allowed to actively design their own experiments in a 3D virtual world and explore them. The system provides various facilities for students to analyze different physics quantities of the target object before, in and after the experiment, such as forces, weight, motion path, etc. However, the system requires some expensive equipment such as helmets, 3D glasses, etc. Martín-Gutiérrez et al present an application of Augmented Reality to help engineering students improve their spatial abilities. They designed a book called AR-Dehaes which can exhibit 3D models to help students fulfill their virtual tasks, attempting to elevate their spatial skills during a short-time remedial course. A replication experiment participated by 24 freshmen proved that the training has measurable positive effects in improving students' spatial abilities [8]. The famous organization in the field of education, The New Media Consortium (NMC) listed Augmented Reality as one of the six most potential technologies in 2-3 years in both the 2010 and 2011 Horizon Report. And the variation from "simple Augmented Reality" in the 2010 edition to "Augmented Reality" in the 2011 edition has indicated that the technology is growing into maturity rapidly [9-10].

III. SYSTEM ARCHITECTURE

A. Local Augmented Reality Environment

During the evolution of AR, a variety of related research topics have been developed and discussed extensively, including: (1) Tracking techniques; (2) Interaction techniques; (3) Calibration and registration; (4) AR applications; (5) Display techniques [11]. Our system first detects the real scene with a camera, deposits it as the bottom layer, and then calculates the position of the particular marker in real space according to inner and outer parameters of the camera and the 3D registering algorithm. After that, the system looks for the corresponding virtual model to each marker in the 3D model pool and projects it at the position of the marker on the projection surface of the camera according to its projection matrix. Finally, the system synthesizes the image of the projected 3D object and real space and exports the scene image which blends reality and virtuality.

B. Distance Augmented Reality Environment

Online classes based on distance video interaction system passes on knowledge to learners from both visual and auditory sense, which makes up the deficiency of the monotonous learning materials using traditional online courses to some extent. However, the present video displaying system doesn't provide enough interactions between students and learning materials, making it difficult to illustrate some abstract concepts, which suggests that the system still has some limitations in the application of web-based education. We construct a one-to-many learning system based on Augmented Reality in which teachers deliver augmented video information to students at real time based on the internet video interaction system. The overall design of the system is as follows in Fig. 1.

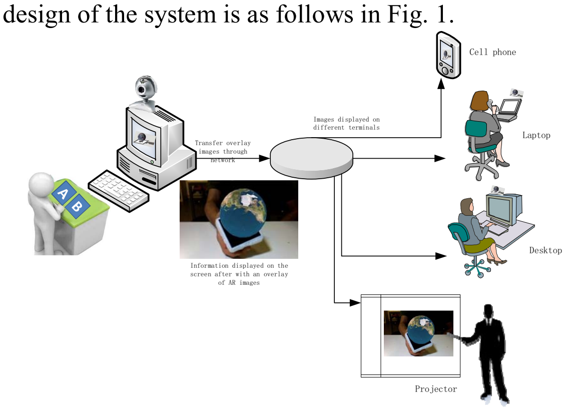


Fig. 1 The Overall Design of the One-to-many Video Learning System

The system supports the following two instructional modes for teaching and learning:

- It supports learners' self-oriented learning. Learners adopt the AR self-learning method, and the only thing they need is a papery marker which can be recognized by the system. The camera will automatically detect the marker, and then undertake the 3D registration and position verification process, to interpose the 3D virtual images on the actual scene on the screen. Students can interact with the 3D objects on the screen through some simple operations, such as moving, overturning and snatching the marker.
- It also supports teacher-oriented teaching activities. Learners get connected to the class through different terminals and then receive the real-time message sent by teachers. AR-aided teaching is able to help teachers illustrate certain abstract concepts which are difficult to convey through words or models not accessible due to financial limitations.

IV. INSTRUCTIONAL DESIGN CASE

Among the many emerging technologies for designing textbooks, AR is considered to be a very potential one. We devised several related cases in education with the help of AR, and assembled these cases into a book called "Book in the Future" [12]. It requires a computer and a camera. The camera will detect the markers on the book, and then 3D virtual scenes will arise. It's considered to be a real blended 3D interaction book. We have selected several representative cases as follows.

A. Newton's First Law of Motion Simulation

"An object at rest tends to stay at rest and an object in motion stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force."—this is Newton's First Law of Motion. Practical teaching of this theory is mainly conducted by doing experiments. However, when the teacher is displaying, it is almost impossible for every student to observe the experimental phenomena clearly, and the reassembling of the experimental equipment might take up a lot of time in class. Furthermore, the interferential factors in the experiment can't be removed, thus making the condition less ideal. Students' exploration opportunities are also lessened if the experiment is displayed by the teacher.

We designed and developed the AR-based experiment model for Newton's First Law of motion, and finished the corresponding instructional design with the help of teachers in physics. The model is shown in Fig. 2. We placed three combinations of an inclined plane and a horizontal board, which are exactly the same except that the friction coefficient of each board is different. The small car slides down along the plane due to gravity until the horizontal board and moves on. Because of the friction force on the board, the small car speeds down. Owing to the difference of friction coefficient, the distance the car can reach on the board varies. The smoother the board is, the less resistance the car faces, the slower its speed decreases and the farther it moves. It's thus deduced that if no force is acted on an object, it will stay in motion with the same speed without any stop.

Fig. 2 Newton's First Law of Motion Simulation

Learners can make more conjectures about the experiment. By changing experimental parameters observing and recording experimental phenomena, they can examine their hypothesis. For example, in this case, learners can investigate into this experiment independently by varying the friction coefficient of each board and explore the relationship between the distance the car moves and the horizontal resistance. It's possible that the horizontal resistance is set as f=0, and Newton's First Law of Motion is then acquired. The smaller the resistance is, the longer distance the car stays in motion. If no force is acted in the process, the car will stay in motion with the same speed forever.

B. Newton's Second Law of Motion Simulation

"The acceleration of a body is parallel and directly proportional to the net force F and inversely proportional to the mass m"—this is the Newton's Second Law of Motion. Similar with the First Law, we have also developed the experiment models for Second Law.

As shown in Fig. 3, in this scene, we set an absolute smooth board and place the car on this board. The car is tied with a string which gets round the crown block and is loaded with weights. Due to the gravity of the weights, the car will move on the absolute smooth board under the stress from the string. The value of the stress is considered to be the same as the mass of the weights (the scale pan included). The mass of the car and the value of the stress can be varied by adding or removing weights. When the back-end of the car is also tied with a string, we can use a clamp to clip two strings, thus controlling two cars at the same time, in other words, making them start and stop at the same time. We set three cars in this experiment model. When their masses are the same, the larger the stress is, the quicker it runs, i.e., the acceleration is bigger. On the other hand, when they undertake the same stress, the smaller its mass is, the quicker it runs, i.e., the acceleration is bigger as well. It's thus concluded that, the acceleration is parallel and directly proportional to the net force F and inversely proportional to the mass m.

Fig. 3 Newton's Second Law of Motion Simulation

Similar with the instructional design for the First Law, we provide more interaction activities for learners. They can change the mass of both the car and the weights, i.e., the stress on the car, and also other experimental parameters, to observe the variation of phenomena to examine their own hypothesis.

C. Simple Pendulum Simulation

As is shown in Fig. 4, we use an absolute flexible, length-immutable and weight-negligible string to hang a particle. The particle complies periodic motion in the vertical plane, which is called pendulum. When the oscillation angle of the pendulum is smaller than 10°, the motion can be considered as simple harmonic motion.

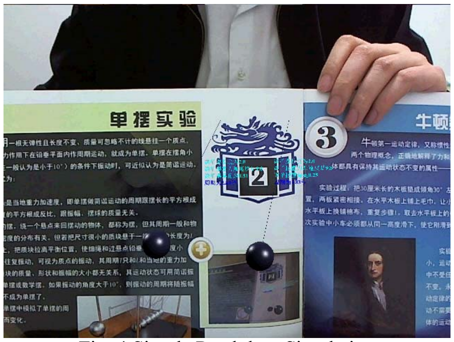


Fig. 4 Simple Pendulum Simulation

The periodic formula of the simple pendulum is

$$T = 2\pi\sqrt{l/g} \quad (1)$$

In the formula, l stands for the length; g stands for the local acceleration of gravity. The formula indicates that the cycle of the pendulum is proportional to the square root of its length and is inversely proportional to the square root of the acceleration of gravity, which has nothing to do with amplitude and the mass of the ball.

In the AR-based learning environment, learners can examine whether the pendulum is under simple harmonic motion by varying the oscillation angle. Learners can also deduct the critical condition for the pendulum to comply simple harmonic motion with similar methods. Moreover, in the teaching process, students can work on several control groups with different length and acceleration gravity to attest the periodic formula of pendulum.

D. Ants Meeting Algorithm Simulation

Ants Meeting is from a recruitment topic of some company. It is described as follows:

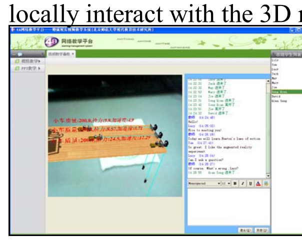
- Assumption: There are infinite ants on a rod. If two ants meet, they turn to the opposite direction until the end of the rod and then fall down. It takes 5 minutes for an ant to run from one end to the other.
- Question: How much time do all the randomly distributed ants fall down?

It can be a quite complicated question if worked out through stringent mathematical deduction. However, we can solve it through discrete method. We implement an AR program to simulate the Ants Meeting algorithm where there are 4 ants, 32 ants, 128 ants and 200 ants. Assuming the length of the rod is 3 meters, and the speed is 0.2 meters per second. Then it takes 15 seconds for an ant to run from one end to the other on the rod. From the simulating result, we can see if the number of ants is infinite, the finishing time is close to 15 seconds. Fig. 5 is the simulation experiment where there are 32 ants.

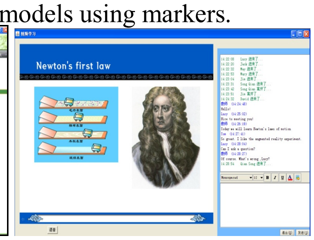
Fig. 5 Ants Meeting Algorithm Simulation

V. Distance Education

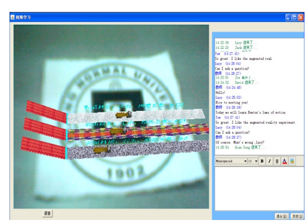
Based on the environment of Augmented Reality, we developed the distance augmented video instructional system. When learners are connected to the server as terminals, they can receive messages at real time from teachers. Take the illustration of Newton's Law as an example, augmented reality videos can work as an effective implementation to the traditional teaching method using slides. Students will get a better understanding of the static knowledge in their textbooks by acquiring real-time augmented video information. (Shown in Fig. 6 (a), (b), (c)). On the other hand, students can choose not to connect to the server. In this case, they initialize their own augmented reality system, and locally interact with the 3D models using markers.



(a)



(b)



(c)

(d)

Fig. 6 Distance Video

(a)The teacher's side; (b) the student's terminal receives the instructional information from the teacher' s PPT; (c)the student's terminal receives the augmented video from the teacher's side; (d) using mobile devices to receive augmented video

The system also works on mobile terminals. Students can study with augmented videos using mobile devices anywhere at any time. Fig. 6(d) shows the scene of receiving augmented video on Motorola mobile phone with Android operating system.

VI. EXPERIMENTS AND ANALYSIS

According to the application mode of the AR-based video instructional system we have constructed, we conducted a case study on a physical experiment class. We launched the research in an ordinary middle school in Tianjin Nankai Foreign Language Middle School, the students' overall performance of which lies in a medium level in the city. Firstly before the class, we made an interview to find out the key points of this section in the teacher's teaching process and the main problems students came across during their learning process. Through the interview, we conceived that we should not only teach students physical disciplines but also equip them with a preliminary concept of the methods of scientific research, strengthening their independence and activity in learning. We emphasized self-oriented learning, and our class adopts the combined teaching mode of experiment and theoretical proof. In other words, students conduct experiments in an Augmented Reality environment at first, and then teachers guide them to finish the proof of convex imaging rule through classroom teaching.

After the class, we conducted investigation with questionnaires to students who used our system. The questionnaire aims at investigating students' interests and attitudes towards utilizing teaching tools based on AR. The total number of questionnaire distributed is 32, and 31 of them are received, among which 30 are effective, resulting in a 96.8% coefficient of recovery and 96.8% percent of pass. There are 14 boy-students among the respondents of the questionnaire received, accounting for 46.7% of the total number, and the rest are girls, accounting for 53.3% of the total number. The questionnaire consists of 14 objective problems (which require students to choose an appropriate option for the statement from "totally congruent" to "totally incongruent") and 3 subjective problems (mainly concerned with students' experience in the class and their suggestions towards our AR-based instructional tool).

According to the analysis of the statistical results, we obtain a general positive response and students show great interest in the application of AR-based learning system in class. We primarily analyzed the results from two perspectives, the influence of AR-based video instructional method on students' learning interests and their learning outcome. 80% of the students tested admit that the experiment displayed using Augmented Reality in their physics class stimulates their curiosity, which encourages them to explore deeply into the subject. 64% of the students tested prefer AR-based instructional system to help them study to the traditional classroom teaching method. 70% of the students tested indicate that they were not absent of mind during the class. 60% of the students tested consider that they generalize the physical experiment discipline on their own, 33.3% are uncertain, and the rest conceive teachers and their classmates helped them. 76.7% of the students tested express that they can remember the experiment conclusions taught in class.

It's true that a virtual laboratory can accomplish the aforementioned demonstration as well, whereas from the surveys we conducted on virtual experiments before, we found that students' learning achievements are not excellent as expected. They can correctly grasp some concepts in formal classes, yet learning results in pure virtual environment are not ideal. In response to these phenomena above, our explanation is that in a 3D learning environment, students whose self-control is not developed, with great curiosity towards virtual learning platforms, may be easily distracted by irrelevant objects and accidents, such as chatting and wandering in the 3D scene. Furthermore, traditional virtual environment presents users with a feeling of division, and they may feel everything is artificial from the very beginning. By contrast, Augmented Reality overcomes all these deficiencies. In an AR-based environment, as users have discarded mouse, keyboard, etc, and adopted a natural interactive method, which provides the same operation experience as in real scene, they can experience a completely innovative and fascinating learning method which interposes virtual objects that are limited by expenses, safety or other factors to present in real life and the feeling of division is thus removed.

VII. CONCLUSION

Our blended learning environment eliminates the complexity of Augmented Reality technologies. Only a computer or other mobile device with a camera will realize real-time interactions between students and 3D virtual learning materials based on AR, which satisfies the instructional requirements of the interaction and the exemplification of abstract knowledge during local or distance video instruction process.

Finally, we have predicted the trends of blended learning environment as follows,

Firstly, it will enable users to participate in the composing process. Blended learning environment returns the rights of composing learning materials to users. Learning contents and activities are both designed and accomplished by users, which indeed embodies the concept of user-centered.

Secondly, more exploration space will be provided. When teaching activities are migrated into an AR-based environment, traditional interactive methods may not be suitable. How to design teaching activities, how to realize better communication between learners, etc are all questions to be discussed and solved by developers and users of the blended AR environment.

Thirdly, it will combine with learning management system. How to integrate the AR-based learning environment with existing 2D information systems and 3D virtual environments requires further exploration into how this integrated environment elevate learning outcome and keep with existing and new teaching methods.

Fourthly, it will merger with intellectual technologies. Ideal blended learning environments can imitate real teachers' experience, methods and behaviors, automatically fulfilling the task of analyzing and explaining students' questions.

Finally, it will connect with mobile technologies. The AR application on mobile device remains on a 2D level such as geographical positioning. How to let learners enjoy mobile learning anywhere at any time and at the same time bring them the 3D learning experience of AR on computer needs unyielding efforts from both technicians and educators.

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