A Realistic E-Learning System based on Mixed Reality

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Abstract. In this paper, we describe an E-Learning system based on the mixed reality. Mixed reality provides users with immersion, presence, and additional information suitable for the current context. That point results in many researches applying mixed reality to education field. However, they have been just prototype systems or experimental systems. In contrast with the previous works, our system is the total solution for a mixed reality based E-learning system at commercial level. It has three large components: the client system, the learning management system and the authoring tool. It also requires the robust marker recognition for commercialization. In this research, we focus on this part. With this system, we have conducted the user study with K-4 and K-5 students. As a result, we could confirm that our system enhances the students' interest in lesson and the educational achievement.

Keywords: Augmented Reality, Mixed Reality, E-Learning

1 Introduction

This paper describes a mixed reality based E-Learning system for enhancing the learning effect with immersive and realistic sense. Mixed reality can offer new formats compared to traditional educational strategies of teaching, reading, and hearing. It also allows students to become an integral part of their own learning process, to allow them to experience new systems instead of simply reading or hearing, and moreover to pretend to work and learn in various situations without risk.

Some mixed reality applications have already been presented in education field. They have been just prototype systems or experimental systems. However, our system is the total solution integrating the client system, the authoring system, and the LMS (Learning Management System) on the web.

Fig 1 shows the configuration of a mixed reality based the E-Learning system. Teachers can make teaching materials with the authoring system and upload them to the LMS system. The role of the LMS system is to manage teaching materials and users' accounts/activities by communicating with the client system. The core part of the whole system is the client system which renders 3D models of teaching materials, interacts with interface devices and recognizes markers in real books. These markers are used for locating and identifying the rendered 3D models. Markers are classified into two types: one is for locating 3D models and the other is for handling 3D models. We call the former 'fixed marker' and the latter 'control marker'. In order to commercialize a mixed reality based system, the marker recognition process should be very robust to various environments and users unfamiliar with mixed reality.

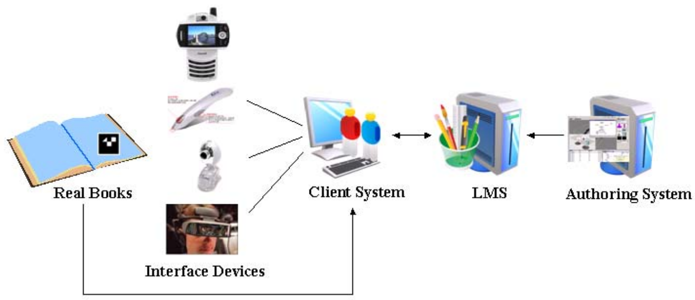

Fig. 1. The configuration of an E-Learning system based on Mixed Reality

2 Previous Work

The Magic Book [4] is well known for the first replacement of the real books by the realistic and immersive learning materials. The Magic Book was created by HIT Lab. at the University of Canterbury. The Magic Book looks like an ordinary storybook with colorful pages and simple text. However, when users look at the same pages through a HMD, 3D virtual objects emerge from the pages. You can still see the real world book, as well as everything that is going on around you, just except a little virtual scene which sits on the page. Shelton and Hedley [5] presented the research to teach students the relationship between the sun and the earth using AR. In this research, the important thing is to show their relative positions in space. The AR technology allows users to understand deeply and easily about their relationship because AR is appropriate for showing 3D relationship. Several years ago, researchers of Electronic Visualization Laboratory at the University of Illinois at Chicago installed the CAVE system for virtual reality at Abraham Lincoln Elementary School. The Round Earth Project [6] included the user study which verifies whether the virtual reality technology is an effective teaching tool for students or not. Though the project was organized with the virtual reality technology, it gave us strong possibility to apply a new technology to the teaching method for K-12 students.

The difference between our system and all related works is that our system has the total solution for an E-Learning System based on Mixed Reality so that it aims at commercialization.

Our paper is organized as follows: In section 3 we will describe the proposed system architecture and design scheme. In section 4 we will focus on describing the marker recognition process as the core part for the mixed reality. In section 5 we will show the results and finally conclude in section 6.

3 The Architecture of the Proposed System

As shown in Fig 1, the E-Learning system based on the mixed reality technology consists of 3 large components: the client System, the learning management system, and the authoring system. In this section, we describe the detail architecture and functions of each component

3.1 The Client System

The Client System based on the mixed reality technology is the core part of the total system. It is composed of the Maker Recognizer, the Realistic Contents Manager, and the Viewer. When a sequence of images is entered from a camera, the Marker Recognizer conducts the marker recognition process for identifying markers and estimating the pose of markers (6 DOF: 3 for translation and 3 for rotation). The Realistic Contents Manager manages 3D models, textures, mapping, sound, video, and so forth. It is a very important module for dynamic and real time insertion and deletion to the scene graph. The last module in the Client System is Viewer. The scene graph is represented by VRML format and rendered with OpenGL graphics engine. It also renders the sound and video data as well as the graphic data. (Fig 2. left)

3.2 The LMS (Learning Management System)

The role of the LMS is to manage the realistic contents and the users' accounting and profiling data during learning and teaching. Students login the LMS using their IDs and passwords, and then the Client System downloads the realistic contents from the LMS. After that, students can study with the client system and students' activities are transmitted to the LMS during study. These data play a crucial role in the evaluation of educational achievement. (Fig 2. middle)

3.3 The Authoring System

The Authoring System is the tool for creating and editing the teaching materials. 3D contents are created by using a 3D modeler such as 3D MAX or MAYA and imported into the Authoring System by the customized VRML import plug-in. With the Authoring tool, teachers can select some required markers and create the links between the markers and the realistic contents including 3D models, movies and audios. Moreover, the tool supports the action script, so that various complicated scenarios appear to be possible. For example, the realistic contents may be rotated or magnified when a certain control marker is close to them, or a certain movie and audio may be played if the realistic contents is moved and located at the appointed position. (Fig 2. right)

In the authoring system, the considerable point is the user interface of the tool because novices or teachers unfamiliar with IT may handle this system.

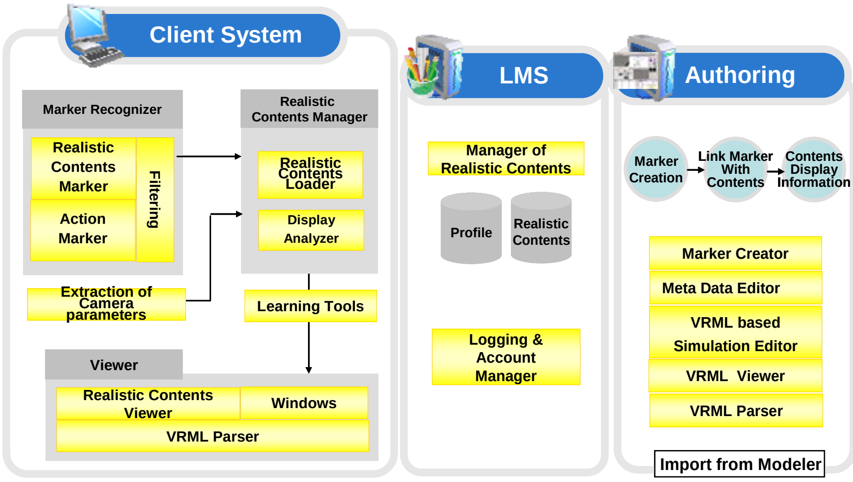

Fig. 2. (left)The System Architecture for Client System, (middle)LMS and (right)Authoring System

4 Marker Recognition Process

The system obtains the image including some markers by a camera and detects quadrangles from the image. Those are candidates of markers. To classify real markers among candidates, the system recognizes patterns of quadrangles. The candidate including a pattern ID is to be accepted as a real marker, and then pass the pose estimation process. The system returns the projection matrices and the pattern IDs of the markers as final results. Those are used to superimpose some virtual objects onto the image captured by a camera.

4.1 Quadrangle Detection

The representative marker recognition system, ARToolkit [1] performs image binarization based on the fixed threshold to detect quadrangles. This method, however, has a weakness for variant lighting conditions. Due to that problem, some marker recognition systems determine the threshold adaptively. Unfortunately, those also have a weakness for uneven lighting conditions such as shadows. To overcome those problems, we use the edge-based method, which is more robust to variant lighting conditions and partial occlusion. Fig 3 shows that the system is able to detect quadrangles even in partial occlusion and dark lighting condition.

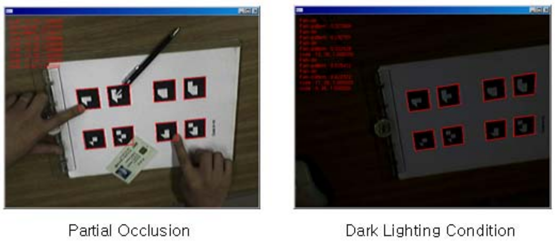

Fig. 3. Quadrangle Detection in various environments

4.2 Pattern Recognition

As mentioned above, the system needs to support systematic coding of marker patterns corresponding to many pages of textbooks. Moreover, it is able to recognize various iconic patterns; we also define total 256 fixed patterns which are applied to systematic coding, and allow users to define their own patterns which help users to notice the meaning of markers intuitively. Fig 4 shows some fixed patterns and iconic patterns.

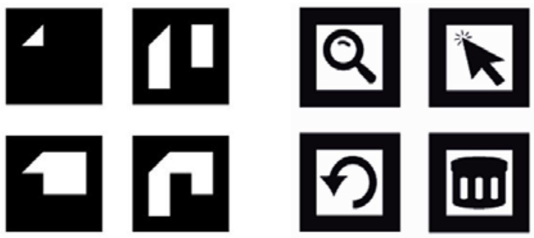

Fig. 4. Fixed and Iconic Patterns

Markers have a black boundary line with a square shape, in which a pattern is included. A fixed pattern is divided into the 9 section. The upper left one (the direction bit) is most important among the 9 sections. It eliminates symmetry of markers and moreover allows the system to distinguish between the fixed patterns and the iconic patterns. The other 8 sections represent a pattern ID, and correspond to 8 bits in the binary system. If one among them is filled with black, the corresponding bit is to be 1, otherwise, 0. For example, if the 5th and the 6th bits of the fixed pattern are filled, the pattern represents 0011000 in the binary system, which is 48 in the decimal system.

To recognize patterns the system finds the direction bit in the detected quadrangle. If there exists the direction bit, the pattern in the quadrangle is decoded to find the pattern ID, otherwise, it is likely to have an iconic pattern. To find an ID of an iconic pattern, the pattern is compared with the pattern database. PCA is used to reduce the dimension of patterns. If there does not exist a similar pattern in the pattern database, the quadrangle is eliminated from candidates of markers.

The important thing of pattern recognition is to reduce the false-positive rate and the confusion of patterns. If there are errors in pattern recognition, it occurs that the system superimposes undesirable contents onto the image. That is fatal to the commercializing a mixed reality system. In this research, color and edge information are used to reduce errors in pattern recognition process.

4.3 Pose Estimation

In this research, we use an object-space collinearity error as the error metric [7].

$$\mathbf{Error} = \sum_{\mathbf{i}=\mathbf{1}}^{\mathbf{4}} \left\| (I - \hat{V}_i)(Rp_i + t) \right\|^2, \qquad \mathbf{(1)}$$

$$\textbf{where } \hat{V}_i = \frac{\hat{v}_i \hat{v}_i^t}{\hat{v}_i^t \hat{v}_i}$$

In the error, $\hat{v}_i$ is the observed image point, $\hat{V}_i$ is the observed line-of-sight projection matrix, and p_i is the model point. R and t means rotation and translation of a camera respectively. The more accurate the system estimates the pose of the camera, the less the object-space collinearity error.

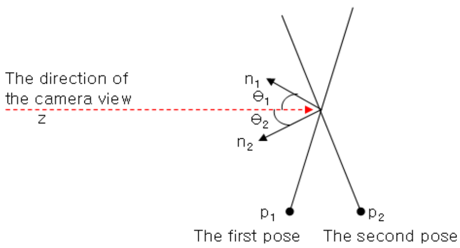

Fig. 5. The first pose and the second pose

Our pose estimation algorithm is motivated by the Schweighofer and Pinz's work [2]. They pointed out that there exist two local minima of equation (1). We found that Θ_1 and Θ_2 are similar, where Θ_1 represents the angle between the camera direction and the normal of the marker's pose with the first local minimum, and Θ_2 represents that with the second one (Fig 5). We assume therefore $\Theta_1 \approx \Theta_2$.

To calculate the marker's pose with the first local minimum, the system calculates the initial pose by using direct linear method [3]. To minimize (1), The orthogonal iteration method is used [7], where the above result is used as the initial value. By the assumption, $\Theta_1 \approx \Theta_2$, we could roughly transform the first pose into the second one.

The transformation matrix, M is calculated by rotating $2\Theta_1$ round the normal vector of the plane including n_1 and $-z$, where z means the direction of the camera view.

$$\mathbf{M} = \mathbf{I} + \sin(2\theta_1)\mathbf{A} + (1-\cos(2\theta_1))\mathbf{A}^2, \tag{2}$$

$$\text{where } \mathbf{A} = \begin{bmatrix} 0 & -\mathbf{n}_{r3} & \mathbf{n}_{r2} \\ \mathbf{n}_{r3} & 0 & -\mathbf{n}_{r1} \\ -\mathbf{n}_{r2} & \mathbf{n}_{r1} & 0 \end{bmatrix}, \begin{bmatrix} \mathbf{n}_{r1} & \mathbf{n}_{r2} & \mathbf{n}_{r3} \end{bmatrix} = \frac{\mathbf{n}_r}{|\mathbf{n}_r|},$$

$$\text{and } \mathbf{n}_r = \mathbf{n}_1 \times -\mathbf{z}$$

The marker's pose with the second local minimum is calculated simply by $P_2 = MP_1$, where P_1 and P_2 are the projection matrix of the first pose and the second pose, respectively. The object-space collinearity error of the second pose is also minimized by the orthogonal iteration method like the first pose. Lastly, the object-space collinearity error of the first pose is compared with that of the second one. The pose with the less error in both is to be the final pose of the marker.

5 Results

We developed a textbook for elementary school science and English for the user study, and had some lessons for 4 and 5 grade students of elementary school. The science textbook contains 4 books and they include the structure of the earth, the atmosphere, astronomy, and so forth. The English textbook takes aim at distinguishing L and R pronunciations. Fig 6. left shows two kinds of textbooks. We also developed teaching materials using the authoring tool (Fig 6. middle). They were uploaded into the LMS, so students could download. Fig 6. right shows how the viewer of the client system looks.

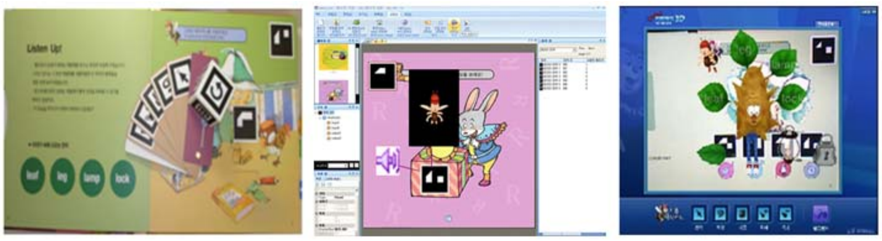

Fig. 6. (left)The English textbook, (middle)the authoring tool and (right)the viewer

The real class work was held at the Christian elementary school in Suwon. Total 180 students of 4 and 5 grades took the class in the computer lab of the school, and made the worksheet for surveying the attainment.

As a result, almost teachers and students were very interested in mixed reality which is new and immersed in the system. The measurement of learning was also high. However, sometimes people felt hard to control 3D contents with control markers because of the shortage of the intuition. This noticed us that we need more intuitive interface better than the control marker for next version.

6 Conclusion

We developed a commercial-level realistic E-Learning system based on mixed reality. We also suggested a total solution including production and distribution of the realistic contents, not just for showing. The Authoring System was developed to be easy to make contents for novices like teachers who are unfamiliar with IT. The LMS is for distributing the realistic contents, analyzing the students' activities, and evaluating the educational achievement. To develop an E-Learning system based on mixed reality at commercial level, robust marker recognition is needed. It must recognize markers in users' various environments, and conduct the stable pose estimation of small-sized markers because users feel unnatural and uncomfortable with the printed markers. It also needs systematic coding for marker patterns corresponding to many pages of textbooks, and iconic patterns which give users intuition. Our system satisfies these conditions.

Using the proposed system, the user study with many K-4 and K-5 students was conducted. For the user study, we made commercial level test books and teaching materials by using the authoring tool. As a result of the study, it is found that the mixed reality technology helps to draw more students' interest, and enhance the educational achievement.

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