An Immersive Augmented-Reality-Based e-Learning System Based on Dynamic Threshold Marker Method

Sukhyun Lim and Junsuk Lee

In recent years, augmented reality (AR) technologies have been the subject of great interest among many communities. In education applications, old-fashioned materials (or textbooks) are still used, despite remarkable AR developments in the industrial area. We present an AR system for education. Our system consists of an authoring tool that can be used to create educational content, a viewer that plays that content, and an engine to manage the tool and viewer. In our system, a marker unit recognizes a marker printed on a plane or a cubic plane by adaptively adjusting the threshold to have an excellent recognition rate in diverse environments and acquires corresponding data of the marker. Based on the system, we test 142 elementary school students for increased educational benefits using our system.

Keywords: Augmented reality, e-learning application, authoring tool, multimedia tool, marker recognition.

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I. Introduction

Many of us need to gain a new perspective on English education in Korea and to see classroom activities as an interactive learning experience for both students and faculty. The traditional approach to this education has been to teach discipline-oriented material. Because English is not the native language of Korean students, it is difficult to teach reading, writing, and speaking in English. We have received feedback from many elementary students that tells us they find it more interesting to learn English through methods that do not involve using textbooks.

Augmented reality (AR) is a technology that allows virtual images to be seamlessly mixed with the real world [1]-[4]. AR stands between virtual reality and a real environment [5]-[7]. On the contrary, augmented virtuality (AV) is a technology that enhances the user's reality by inserting a real object into a virtual environment (see Fig. 1).

The AR and virtual environments are divided depending on whether the environment or object in the real world appears or not. Hence, AR requires an input device (for example, a video camera or webcam) to receive input from the real world, and the input should be meticulously constructed so that the user cannot distinguish the virtual world from the real world [8]-[10]. In addition, AR has real-time properties, since the user should be able to watch the screen on the spot. Because the screen with the AR unfolds right in front of the user, they have a higher level of immersion in the AR than they do with other technologies.

An e-learning system is based on a telecommunication

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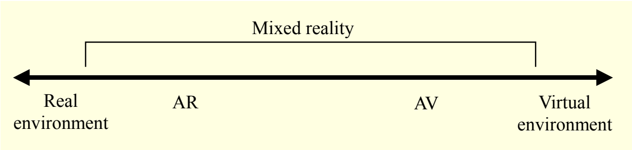

Fig. 1. Taxonomy of mixed reality including real to virtual environments [1].

technology that delivers customized learning to the user, enabling anyone to experience a learning activity that perfectly fits their needs, at any time, and anywhere. During the early days, the concept of e-learning was usually confined to an educational method that supported only internet-enabled learning. For the implementation of e-learning, we require three factors, known as the 3C development of e-learning: content (learning materials), connectivity (delivery of the content), and community [11], [12]. Content refers to learning materials or supplemental learning resources, and connectivity refers to various delivery systems and an e-learning support system, which are necessary to connect the learner to the content. Connectivity includes the hardware and software for e-learning, a system infrastructure related to the network, an e-learning platform to support the e-learning environment, and an authoring tool to develop e-learning content.

The community consists of students, instructors, and operators, all of whom cooperate with each other through active communication based on the infrastructure and content [11], [12]. The service of e-learning is divided into the following three types: cyber lecture/VOD type, worksheet/test type, and Q&A/database type. The VOD type refers to a system that transmits content from the database to the user's device. The worksheet type refers to a service that delivers learning materials in a worksheet or provides personal tutoring via e-mail. The Q&A type is a system in which the learner asks questions regarding the learning materials and is subsequently provided with answers on the Internet. Most of the current e-learning systems are running a mixture of these types. As for the concept of e-learning, it is generally fixated on the VOD service. However, so far, e-learning has played the role of a one-way delivery of knowledge to the user, which has resulted in a boring and tedious educational environment wherein the learner is forced to passively absorb the delivered knowledge. While this previous paradigm is focused on a one-way teaching process in which the student passively accepts information delivered by the instructor for the purpose of memorizing and retaining as much knowledge as possible, the new paradigm demands that education cultivate the student's ability to create knowledge with added value themselves [13]. Hence, the e-learning system and e-learning environment should also promptly adapt to the new educational paradigm.

This paper proposes an e-learning system based on AR technology, in which the learner can lead their learning activities by interacting with the content. To build an e-learning system, we require an engine that can run the learning content using AR. Then, using the engine, an interface learning viewer for the learner and an authoring tool used in creating AR content are required. The proposed system shows augmented 3D objects to the learner using a camera and other interaction tools. For example, the system can show the shape and function of an object that the learner cannot actually describe in English. Particularly if the learner is a child, they can be deeply immersed in the educational content.

When the student places our system in front of a camera connected to a PC, the system seamlessly synthesizes the captured image with 3D visual contents, and the student can see the synthesized image through a monitor. As with other AR systems, the major problem is the registration between the real and virtual worlds. Registration of both worlds involves page recognition and six degrees of freedom pose calculation. Moreover, to respond quickly to the activity of the user, such as a page movement or a page turn, the registration has to be performed at a minimum rate of 25 fps. There is a conventional marker recognition system, which recognizes a 3D marker in a real image using a Cartesian coordinate 3D marker. Also, there is another conventional technology for improving the performance of extracting a marker ID. However, there are several problems in realizing a learning system by combining conventional marker recognition methods with the AR technology. The first problem is that the system must handle a large number of pages in a book and perform quickly and robustly even on PCs with low computation power. Moreover, a marker recognition technology is required to be robust in various camera and illumination environments.

To build such a system, we first construct the connectivity, one of the 3C factors of e-learning. So, we create an engine that can run the learning content using AR. Then, using the engine, we develop an interface viewer, which the learner uses for learning, and an authoring tool, which is used in creating AR content. The content developer can easily create immersive learning content using our tool. Along with these technologies, we also create an e-learning community [14]. Meanwhile, even the best system is of no use unless it is equipped with appropriate content. The most important thing for an e-learning system is high-quality content. The community is the very component necessary for creating such high-quality content. We make a learning community with a number of experts in diverse fields and make active use of that community.

Authoring tools can provide different levels of assembly functions and control over the relationships between real and virtual objects. Similar to conventional digital content creation,

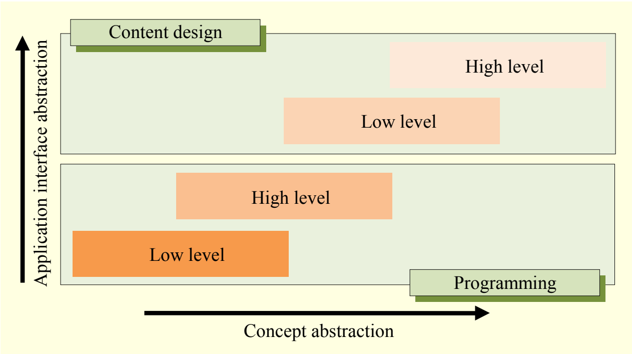

Fig. 2. Schematic view of digital media authoring.

a tradeoff must be made between low-level programming-driven systems and high-level content-based systems, affecting various aspects of the actual product (see Fig. 2) [3]. This view provides different levels of control by predefining underlying concepts.

Several authoring tools for building desktop AR applications exist. These can be broadly organized into two types: 1) AR authoring tools for programmers and 2) AR authoring tools for non-programmers [15]. Authoring tools for programmers are typically code libraries that require programming knowledge, whereas tools for non-programmers include drag-and-drop interfaces to build applications without writing any lines of code. These categories can be further organized into low-level tools that require coding/scripting skills and high-level application builder tools that use high-level libraries or visual authoring techniques.

A number of programming libraries enable developers to author AR applications. For example, ARToolKit is an open-source library that provides computer vision-based tracking of black square markers [16]. However, to develop an AR application with ARToolKit requires further code for 3D model loading, interaction techniques, and other utility functions. An example of a high-level programming library is Studierstube, which provides a complete system for developing AR applications [2]. It includes all the functions needed for building an AR application, such as scene graph rendering, networking, window management, and support for input devices and so on. A common feature of these libraries is that they typically require C or C++ programming ability and other development tools to produce the AR content, and they must be used for a relatively long time to produce an AR application. Another set of authoring tools has been developed for non-programmers, such as artists or designers. At the most basic level, tools such as BuildAR allow the user to associate virtual models with visually-tracked AR markers [17]. BuildAR only allows the user to scale, translate, and position objects on markers and see a live AR view. There is no support for object interaction or more complicated behaviors. One of the first AR authoring tools developed to support interactivity is DART [18], the Designer's AR Toolkit, which is a plug-in for the popular Macromedia Director software. The main aim of DART is to support application designers. DART is built to allow non-programmers to create AR experiences using the low-level AR services provided by Director Xtras and to integrate with existing Director behaviors and concepts. DART supports both visual programming and a scripting interface. AMIRE [19] is an authoring tool for the efficient creation and modification of AR applications. The AMIRE framework provides an interface to load and to replace a library at runtime and uses visual programming techniques to interactively develop AR applications. It is designed to allow content experts to easily build applications without detailed knowledge about the underlying base technologies. Common features of these tools for non-programmers is that they use visual programming techniques or simple scripting to support quick prototyping, they are interpretive rather than compiled, allowing for fast redesign of ideas, and they are integrated into other design tools. However, none of these tools can be used for authoring mobile AR applications.

II. Immersive AR-Based e-Learning System

The overall goal of our English course is to use an interactive classroom learning experience wherein the student takes responsibility for not only learning English but for the process by which these skills are assimilated. The process of learning and interacting is stressed as an important part of what is to be learned. In addition, we emphasize the development of critical reading, speaking, and writing skills as useful for learning and practicing English.

1. Rendering Engine and Viewer of Our System

One of the important factors of e-learning systems is interaction with the user. Previous e-learning systems force the user to learn without any interaction. As a result, they are likely to lose interest quickly, and the produced content may end up being useless. Our e-learning system enables intuitive interaction by using the AR method.

Our system is composed of three components: a rendering engine, a viewer for verification of the results of authoring, and an authoring tool (see Fig. 3). Although videos are commonly used as input devices for AR, we employ a PC-based webcam. Our viewer is installed in the computer along with the immersive learning content, and the webcam is connected to the computer. A webcam is distributed to each student so that it can be used for the student's individual learning.

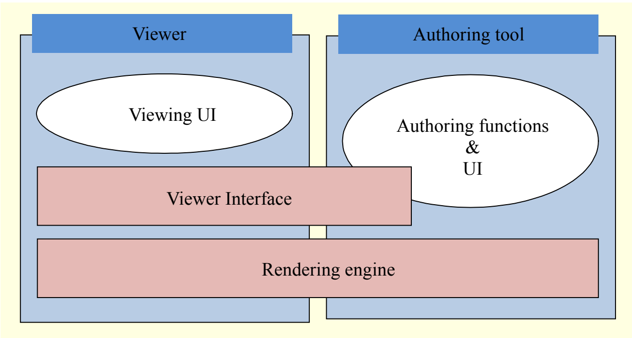

Fig. 3. Conceptual structure of our AR-based system. It has three components: rendering engine, viewer, and authoring tool.

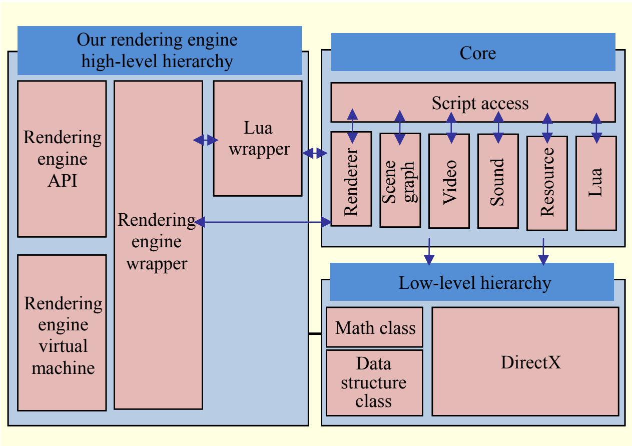

Fig. 4. Diagram of our AR-based rendering engine.

The rendering engine shown in Fig. 4 is composed of diverse functions to implement AR, such as functions for defining planes and inserting a 3D object on a random spot or presenting simple animation using a specific marker. The viewer runs the content created using our authoring tool and presents the video from the input device and augmented 3D videos as the content creator desires. Finally, the authoring tool is made with a number of functions that create the content. In addition, regarding script language necessary for animation of the 3D objects, a script language named Lua script is supported in the authoring tool [17].

Our rendering engine uses DirectX to implement necessary functions. It has two fundamental components: one is a set of mathematical modules for implementing AR using DirectX as a backbone, and the other is a set of data structures used in our engine. In addition, our engine is composed of a renderer, scene graph, video, sound, resources, and Lua process module for the script. As for the functions of the engine, it initializes variables for rendering and computes the projection matrix of the models from the location of the camera to perform rendering. It supports a light and particle system and also processes Lua files for animation and delivers messages.

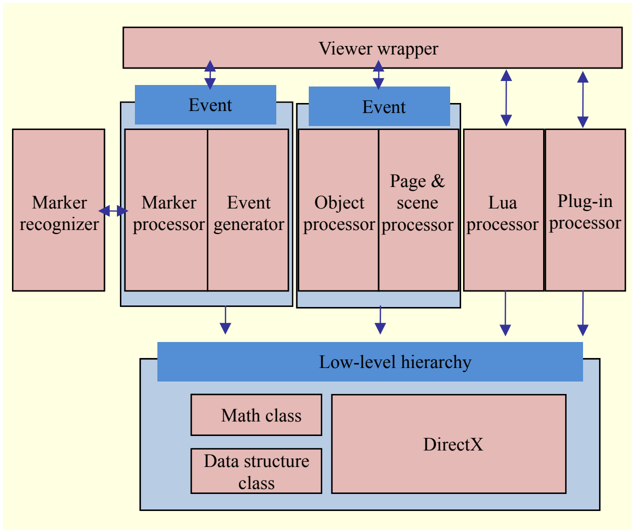

Fig. 5. Diagram of our AR-based viewer.

Finally, it handles the sound and such processes as simple drawings, textures, and models that are used in the authoring tool.

Our viewer has interfaces to reuse the functions that implement the viewer functions that the learner actually uses, and it has a preview function that shows a preview of the authoring process in the authoring tool (see Fig. 5). Also, it delivers the input information from the user (input by a mouse or keyboard). The viewer has a marker recognizer that detects the marker information on the paper via a camera and thereby locates the positions of the detected markers. Furthermore, it has an event generator that generates various events using the information obtained from the marker recognizer. In addition, our viewer is composed of a Data Viewer, which loads the immersive e-learning content created in the authoring tool, to actually perform rendering using the renderer of the rendering engine, a Lua processor that processes Lua script, and a plug-in processor, which runs separately developed library-type plug-ins. Our system has a Viewer Interface for a preview, based on the functions of the rendering engine. Moreover, for an immersive e-learning system, our tool supports the functions to deal with particles and virtual lights. The actions of 3D objects are defined by a script, and we use Lua script in our tool [20]. Since this supports multithreading and its size is small, the processing speed is fast.

A marker recognition unit recognizes a marker printed on a plane or a cubic plane and acquires corresponding data of the marker. There is a conventional marker recognition system that recognizes a 3D marker in a real image using a Cartesian coordinate 3D marker [21]. Further, there is another conventional technology for improving the performance of extracting a marker ID. In this conventional technology, a marker is divided into 36 regions. Then, 10 bits of the marker are used to identify a marker ID, and 26 bits of the marker are allocated as a cyclic redundancy check code to improve the performance of extracting the marker ID.

There are several problems in realizing an e-learning system by combining the above-described conventional marker recognition technology with the AR technology. A marker recognition technology is required to be robust in various camera and illumination environments (for example, flicking phenomenon, which occurs as synthesized virtual contents disappear due to the change in illumination or because a marker printed on the learning material is covered with obstacles). Also, since the learner tends to be uncomfortable with a marker printed on a learning material of a ubiquitous learning system, the size of the marker printed on the learning material is made as small as possible while increasing the recognition rate of the marker. Furthermore, as the number of pages of a book increases, the kinds of markers included in a book become diverse. Therefore, a pattern authoring and recognizing mechanism that can efficiently author and recognize the diverse kinds of markers must be developed. Therefore, we exploit a method for recognizing markers using a dynamic threshold previously developed by our team [21].

After sampling an image of the learning material, image values of the sampled pixels are grouped according to a predetermined threshold (T_i) into a first image group, which corresponds to the color black, and a second image group, which corresponds to the color white. Since the threshold (T_i) is set arbitrarily, it may be updated according to the first image group and the second image group. A new threshold (T_{i+1}) may be calculated by obtaining an average between the median of the first image group and the median of the second image group. Image values of sampled pixels are divided again into a first group and a second group according to the updated threshold (T_{i+1}), and another new threshold (T_{i+2}) may be calculated based on the median of the first group and the median of the second group. In this way, the threshold is updated in the order of T_i, T_{i+1}, and T_{i+2}. If an updated threshold value converges into the previous threshold before the update, further updating stops and it is desirable to distinguish a black part and a white part in the photographic image (binarization) based on the new threshold. To be specific, when the updated threshold is the same as the previous threshold or when the difference between the updated threshold and the previous threshold is equal to or smaller than a predetermined reference value, further updating stops and a black part and a white part of the photographic image are distinguished based on the new threshold. Figure 6 shows the pseudocode used to determine the new threshold. We assume that an image size is $N \times M$ (where N is the number of horizontal pixels and M is the number of vertical pixels), and v_i is the i-th pixel value ($i < N \times M$).

```
compute_i-th_threshold( ) {

        sum_b = count_b = 0
        sum_w = count_w = 0

        for (j=0 ; j<NxM ; j++) {

                if ( v_j <= T_i-1 ) {
                        sum_b += v_j
                        count_b += 1
                }

                else {
                        sum_w += v_j
                        count_w += 1
                }
        }

        T_i = ( sum_b/count_b + sum_w/count_w) / 2
}
```

Fig. 6. Pseudocode used to determine new threshold.

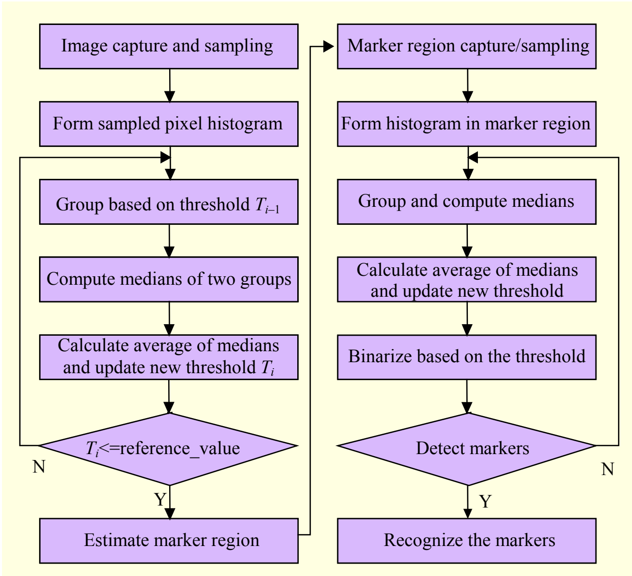

Fig. 7. Block diagram to recognize markers by dynamic threshold marker method.

When an image is binarized according to the above-described dynamic threshold determining method, it is possible to accurately distinguish black pixels and white pixels despite instant or gradual change in illumination. Thus, the marker recognition rate is increased. Our method is advantageous in that it can improve the marker recognition rate. However, the computation required to determine the medians might increase. To solve this problem, after applying this method to the entire image region to find the marker region, we repeat the process of sampling only the region to which the markers belong and update the threshold. Then, we recognize markers by estimating a marker pattern ID based on the edge information and color information. All steps are shown in Fig. 7.

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2. Authoring Tool of Our System

Developing an AR application is usually a long and nonintuitive task. Because suitable tools are lacking, the authoring process is virtually relegated solely to the domain of experts. We proposed our authoring tool in previous work [22]-[24]. The main contribution of the tool was the development of a user-friendly visual tool that enables non-experts, typically engineers, to create AR content quickly and effectively within a familiar 3D modeling environment. To do so, our research team has developed a full set of authoring tools for AR on top of the existing commercial software, either Maya or 3ds Max. The advantage of using such a well-known 3D modeling tool lies in the high level of familiarity within the design environment provided to the user.

Our tool has a Viewer Interface for a preview, based on the functions of the rendering engine (see Fig. 8) [23], [24]. The content created using our tool has the form of “project-page-scene-object.” The authoring tool, once installed, rearranges the layout of the standard graphics user interface tool by providing new toolbars that include the necessary functions to author the AR environment. A new shelf contains a number of new instruments that enable the user to create e-learning content with ease. The user creates the geometries of the environment following the usual process, by either modeling the objects in the scene or loading existing scenes. The user then can select the objects they want (see Fig. 9). The user, through the authoring tool, can create and convert the result to use with our tool at the touch of a button. Then, the user can place marker objects within the scene. When the user creates a new element, some supplementary information required by the final AR setup is supplied.

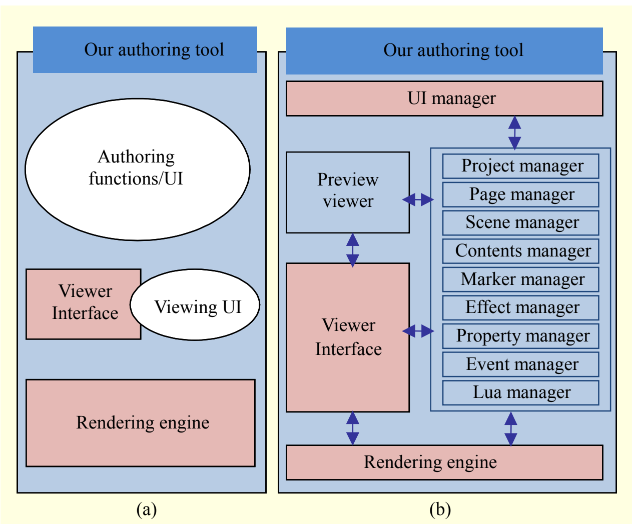

Fig. 8. Diagrams of our AR-based authoring tool: (a) conceptual view and (b) functional point of view.

Figure 10 shows game-like role-play content for Korean elementary students [24]. One well-known approach in this type of content is the use of microworlds; in a microworld, the student achieves specific learning goals through the manipulation of objects within the world. So, role-play content is intended to enable the student to empathize with others, to understand their motivations, and to practice the behaviors being taught [25]-[28].

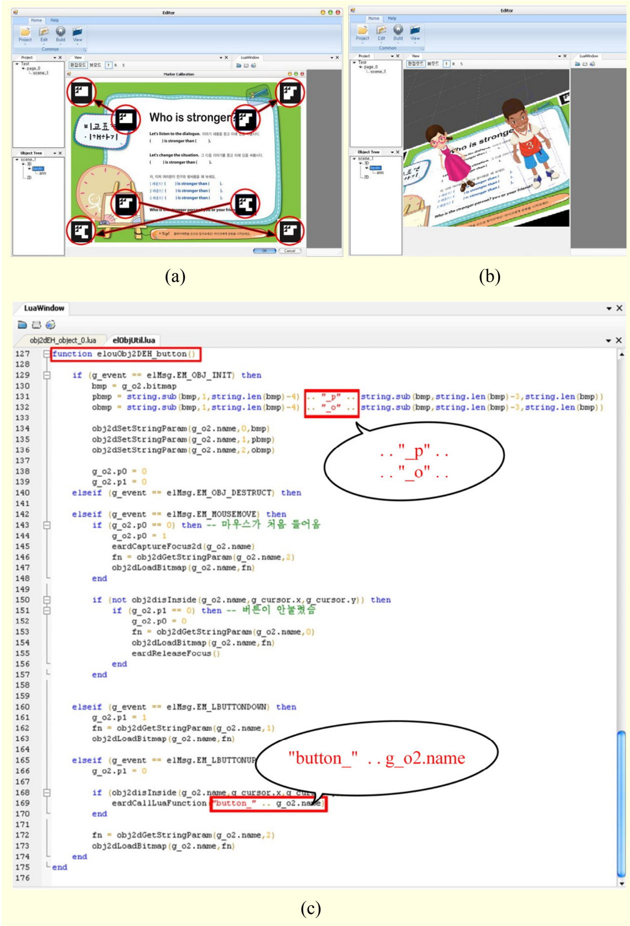

Fig. 9. Screen shots: inserting and manipulating (a) markers and (b) objects by our authoring tool and (c) example of script file for event function. Symbol “_o” represents over event and “_p” represents event for touch or click.

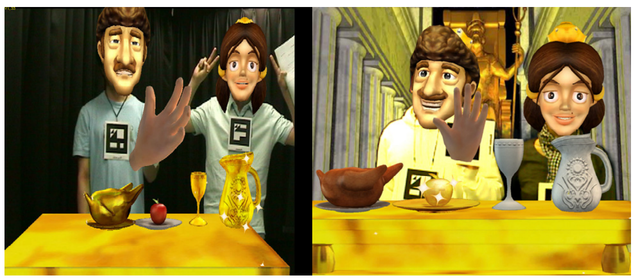

Fig. 10. Examples of role-play content for Korean elementary school students, extracted from King Midas.

III. Experiment Results and Discussion

We attempt to confirm the educational benefit of the system. Currently, in Korean school classrooms, diverse audiovisual data is used in addition to using traditional textbooks. Hence, it is necessary to verify the usefulness of our system. For this purpose, we first request commercial learning materials publishers to create immersive e-learning content for English class. The manufacturers develop content for us based on content proven to be educationally sound. We form a learning community with a number of experts in diverse fields and make active use of the community. The community is composed of researchers at the Electronics and Telecommunications Research Institute, researchers at Korea Studies Information Co., teachers in local schools, textbook companies that specialize in English, an art manufacturer that designs 3D objects for the content, program developers, and college laboratories that develop core technologies. We use the community in a number of ways, including to develop diverse learning activities and to execute research and development. More specifically, it is used to develop high-quality immersive learning content, and diverse interactions are required for the learning process and core technologies to develop the content. The community is also used to apply the system in the actual school environment and subsequently evaluate the performance.

A total of 142 students participate in the experiment. They are from five 6th-grade classes at an elementary school in Daejeon, Republic of Korea. Eighty-six students, accounting for three of the classes, are taught by our AR-based instruction, and the other 56 students, accounting for the other two classes, are taught by traditional textbook-based instruction. We administer three tests.

1. Academic Achievement Test

We generate 25 questions from educational experts. Then, three groups of English teachers validate the test. The test is administered to the participants, and five questions are then eliminated. Each question is worth five points. The pretest is identical to the posttest, to ensure an accurate measurement of achievement. The internal consistency reliability is assessed by computing Cronbach's α and Spearman-Brown's formula results. Cronbach's α reliability is acceptable (α=0.917) and Spearman-Brown's α is also acceptable (α=0.918).

2. Learning Interest Test

The learning interest test is used to measure the student's interest in and preference for learning English. Researchers have focused on two different concepts: individual interest and situational interest [29]. We consider individual interest to be a general interest in learning and situational interest to be a context-specific interest in learning. A test to determine the degree of individual interest is administered before the experiment, and a test to determine the degree of situational interest is administered after the experiment. Our test consists of 24 questions, and the questionnaire has a five-point Likert scale. The internal consistency reliability is assessed by computing Cronbach's α, and its reliability is 0.937. The general learning interest is scored from 20 points to 100 points, and the student receives a grade from 4 to 20 in the posttest.

3. Learning Flow Test

We use the flow state scale defined by Jackson and Marsh as a learning flow test based on Csikszentmihalyi's theory [30], [31]. The questionnaire is made up of 16 questions that consist of effortless control, unselfconscious, time sensing distortion, and autotelic experience, which are the result of the experience, the result of the immersion, and so on. The questionnaire has a five-point Likert scale and has Cronbach's α=0.905. The student receives a grade from 16 to 80.

4. Verification

To verify our system, we perform a *t*-test to confirm the difference between each participant's academic achievement test scores and their learning interest test scores, comparing the classes using AR (called "Group A" hereafter) to the classes using the conventional textbook (called "Group B" hereafter). In addition, we analyze the covariance to investigate to what degree the academic achievement and learning interest of each group is affected. All of these processes are conducted using the SPSS WIN 19.0 package.

Table 1 shows the difference in the academic achievement pretest and posttest scores for both Group A and Group B. According to the value of t using the *t*-test, there is no difference between Group A and Group B. Therefore, we regard them as similar groups in the pretest. The average posttest score of academic achievement for Group A is 86.73, and the score for Group B is 80.20. There is a difference between Group A and Group B (F=16.144, p<0.001). This means that the classes using our AR system score higher on the academic achievement posttest than the classes using only the textbook.

Table 2 shows the difference in the general learning interest pretest and posttest scores for Group A and Group B. The average general learning interest posttest score for Group A is 66.13, and the average for Group B is 65.31. Although there is a difference of about 0.82, it is statistically disregarded (F=0.307, p<0.581).

Table 3 shows the difference in the situational learning

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Table 1. Academic achievement test results for two groups.

Independent variables	n	Pretest score of academic achievement		Posttest score of academic achievement		t	F	p
		M	SD	M	SD			
Group A	86	73.08	27.51	86.73	18.34	0.067	16.144	0.000 (<0.001)
Group B	56	72.77	26.88	80.20	18.03			
Total	142	72.96	27.17	83.47	18.45			

Table 2. Learning interest test results of two groups.

Independent variables	n	Pretest score of academic achievement		Posttest score of academic achievement		t	F	p
		M	SD	M	SD			
Group A	86	64.17	15.82	66.13	14.78	–15.400	0.307	0.581
Group B	56	64.55	11.57	65.31	12.50			
Total	142	64.32	14.25	65.72	13.88			

Table 3. Situational learning interest test results for Groups A and B.

Independent variables	n	Score of situational learning interest		F	p
		M	SD		
Group A	86	14.95	3.71	6.956	0.009 (<0.010)
Group B	56	13.53	3.03		
Total	142	14.24	3.52		

interest pretest and posttest scores for Group A and Group B. The average situational learning interest test score for Group A is 66.13, and the score for Group B is 65.31. There is a 0.82 difference, and there is a statistical difference between Group A and Group B (F=6.956, p<0.01). This means that when we exploit our AR system, the student is more interested in learning English than when using a traditional textbook.

Table 4 shows the difference in the total learning flow test score, effortless control, unselfconscious, time sensing distortion, and autotelic experience between Group A and Group B. We perform a t-test to analyze. The average learning flow test total score for Group A is 57.05, and that of Group B is 51.11. There is a 5.94 difference, and this means that there is a statistical difference between the groups (t=3.494, p<0.01). Each constituent element of the learning flow shows a difference (p<0.01 or p<0.05) between Group A and Group B. Group A receives a higher learning flow test score than Group B.

The following is a summary of the results.

Table 4. Academic achievement test results for two groups.

	Independent variables	n	M	SD	t
Learning flow test score total	Group A	86	57.05	10.974	3.494 (p<0.010)
	Group B	56	51.11	7.963	
Effortless control	Group A	86	14.31	2.825	2.942 (p<0.010)
	Group B	56	13.02	2.102	
Unselfconscious	Group A	86	13.37	3.409	2.344 (p<0.050)
	Group B	56	12.13	2.545	
Time sensing distortion	Group A	86	13.59	3.576	2.198 (p<0.050)
	Group B	56	12.32	3.022	
Autotelic experience	Group A	86	15.77	3.684	3.524 (p<0.010)
	Group B	56	13.64	3.227	

- There is a significant difference in academic achievement between the AR-based instruction group and textbook-based instruction group. The AR-based instruction group accomplishes higher achievement than the textbook-based instruction group.
- There is no significant difference in interest in learning English between the two groups. The questions regard individual interest in learning English. Therefore, because the level of interest in learning English is comparable from one student to the next, there is no significant difference between the two groups regarding their degree of interest in the lessons themselves.
- There is a significant difference in learning flow between the two groups. The AR-based instruction group shows a higher learning flow than the textbook-based instruction group.

IV. Conclusion

We introduced an e-learning system composed of three components: a rendering engine, viewer, and authoring tool. By exploiting the features of our AR system, we easily generated AR content in a very intuitive manner. We confirmed the development potential of the immersive e-learning system through experiments. In our system, the student plays a leading role in their own learning process through autonomous and repetitive learning activities, breaking away from the old-fashioned passive instruction method. So, tremendous educational benefits are produced by our system compared to the previous approach. As a result, we conclude that our content can motivate and inspire interest in Korean students to learn English.

References

[1] P. Milgram and F. Kishino, "A Taxonomy of Mixed Reality Visual Displays," *IEICE Trans. Inf. Syst.*, vol. E77-D, no. 12, 1994, pp.1321-1329.

[2] D. Schmalstieg et al., "The Studierstube Augmented Reality Project," *J. Presence: Teleoperators Virtual Environ.*, vol. 11, no. 1, Feb. 2002, pp. 33-54.

[3] A. Hampshire et al., "Augmented Reality Authoring: Generic Context from Programmer to Designer," *ACM Int. Conf. Proc. Series OZCHI*, Sydney, Australia, Nov. 22-24, 2006, pp. 409-412.

[4] J.M. Andujar, A. Mejias, and M.A. Marquez, "Augmented Reality for the Improvement of Remote Laboratories: An Augmented Remote Laboratory," *IEEE Trans. Education*, vol. 54, no. 3, 2010, pp. 492-500.

[5] B. Barros, T. Read, and M.F. Verdejo, "Virtual Collaborative Experimentation: An Approach Combining Remote and Local Labs," *IEEE Trans. Education*, vol. 51, no. 2, 2008, pp. 242-250.

[6] G.A. Lee et al., "Virtual Reality Content-Based Training for Spray Painting Tasks in the Shipbuilding Industry," *ETRI J.*, vol. 32, no. 5, 2010, pp. 695-703.

[7] M. Sugimoto, "A Mobile Mixed-Reality Environment for Children's Storytelling Using a Handheld Projector and a Robot," *IEEE Trans. Learning Technol.*, vol. 4, no. 3, 2011, pp. 249-260.

[8] D. Hong and A. Mohaisen, "Augmented Transformation for and Empirical Study on Privacy-Preserving Data Clustering," *ETRI J.*, vol. 32, no. 3, June 2010, pp. 351-361.

[9] S.M. Jang, W.H. Choi, and W.Y. Kim, "Client Rendering Method for Desktop Virtualization Services," *ETRI J.*, vol. 35, no. 2, Apr. 2013, pp. 348-351.

[10] D. Jo et al., "Tracking and Interaction Based on Hybrid Sensing for Virtual Environments," *ETRI J.*, vol. 35, no. 2, Apr. 2013, pp. 356-359.

[11] Information and Communications Technology and Disaster Risk Reduction (IDD), "Guidebook on Developing Community E-Centres in Rural Areas: Based on the Malaysian Experience," technical report, ESCAP, 2006. http://www.unescap.org/idd/pubs/Malaysia-CeC-guidebook.pdf

[12] P. Stokes, *e-Learning: Education Businesses Transform Schooling*, white paper, Eduventures.com LLC., Boston, MA, USA, June 2000. http://www.e-learningforkids.org/Documents/Ed_business_transform_learning.pdf

[13] H.-J. Suh and S.-W. Lee, "Collaborative Learning Agent for Promoting Group Interaction," *ETRI J.*, vol. 28, no. 4, Aug. 2006, pp. 461-474.

[14] e-Learning community in Korea. http://www.l2kw.net

[15] Y. Wang et al., "An Authoring Tool for Mobile Phone AR Environments," *Proc. New Zealand Comput. Sci. Research Student Conf.*, vol. 9, 2009, pp. 1-4.

[16] H. Kato, *ARToolKit*, software library, ARToolworks, Inc., Seattle, WA, USA. http://www.hitl.washington.edu/artoolkit/

[17] HIT Lab NZ, BuildAR. http://www.buildar.co.nz/

[18] B. Macintyre et al., "DART: A Toolkit for Rapid Design Exploration of Augmented Reality Experiences," *Proc. Int. Conf. ACM Symp. User Interface Softw. Technol.*, vol. 6, no. 2, 2004, pp. 197-206.

[19] P. Grimm et al., "AMIRE — Authoring Mixed Reality," *1st IEEE Int. Augmented Reality Toolkit Workshop*, Darmstadt, Germany, Sept. 29, 2002.

[20] R. Ierusalimschy, *Programming in Lua*, 3rd ed., Rio de Janeiro: Lua.org, 2013.

[21] S.W. Lee et al., *Method for Recognizing Markers Using Dynamic Threshold and Learning System Based on Augmented Reality Using Marker Recognition*, US Patent Application 20100111405, filed July 1, 2009, published May 6, 2010.

[22] H.K. Jee et al., "An Immersive Authoring Tool for Augmented Reality-Based e-Learning Applications," *Proc. Int. Conf. Inf. Sci. Appl.*, 2011, pp.1-5.

[23] H.K. Jee et al., "An Augmented Reality-Based Authoring Tool for e-Learning Applications," *Multimedia Tools Appl.*, Sept. 2011, pp. 1-11. http://dx.doi.org/10.1007/s11042-011-0880-4

[24] S. Lim et al., "Augmented Reality-Based Role-Playing Contents for Education," *Proc. Int. Conf. IT Convergence Security 2011, LNEE 120*, K.J. Kim and S.J. Ahn, Eds., 2012, pp.337-344.

[25] G. Lee, G. Kim, and C. Park, "Modeling Virtual Object Behavior within a Virtual Environment," *Proc. Int. Conf. ACM Symp. Virtual Reality Softw. Technol.*, 2002, pp. 41-48.

[26] F. Paraskeva, S. Mysirlaki, and A. Papagianni, "Multiplayer Online Games as Educational Tools: Facing New Challenges in Learning," *Comput. Education*, vol. 54, 2010, pp. 498-505.

[27] H. So, L.H. Seah, and H.L. Toh-Heng, "Designing Collaborative Knowledge Building Environments Accessible to All Learners: Impacts and Design Challenges," *Comput. Education*, vol. 54, 2010, pp. 479-490.

[28] J.M. Wisharta, C.E. Oadesb, and M. Morrisc, "Using Online Role Play to Teach Internet Safety Awareness," *Comput. Education*, vol. 48, 2007, pp. 460-473.

[29] U. Schiefele, "Interest, Learning, and Motivation," *Educational Psychologist*, vol. 26, no. 3, 1991, pp. 299-323.

[30] S.A. Jackson and H.W. Marsh, "Development and Validation of a Scale to Measure Optimal Experience: The Flow State Scale," *Sport Exercise Psychology*, vol. 18, 1996, pp. 17-36.

[31] M. Csikszentmihalyi, *Flow: The Psychology of Optimal Experience*, NY: Harper Perennial, 1990.

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