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Virtual Lab Modules for Undergraduate Courses Related to Building Energy Systems

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Abstract

Background: In engineering education, hands-on laboratory experience is essential to enhancing students' practical skills such as conceptual understanding and problem solving skills. However, many students are not able to participate in practical activities (e.g., laboratory experiments) due to inaccessible or unavailable "brick and mortar" laboratories, especially when most universities have currently adopted online instruction while students are sheltered at home due to the ongoing COVID-19 pandemic. **Purpose:** This paper presents a library of virtual laboratory modules expanded and enriched from our initial learning app through an Augmented Reality (AR) environment, where virtual objects (augmented components) are superimposed onto a real learning setting during online lecture instruction. Specifically, to facilitate students' gaining practical skills, a library of virtual objects was established for the main physical components or systems related to the undergraduate "Heating, Ventilating, and Air-conditioning (HVAC)" class to allow students to be immersed in an augmented learning reality representing the real physical world. **Design:** The library of virtual lab modules was established by 1) including all the main HVAC components in an HVAC course; 2) refining these components' 3D models with learning materials (e.g., concept and evaluation); 3) improving the AR method to recognize each component's figures or pictures from any learning document (e.g., printed lecture ppt notes, textbook, and documents shown on computer or mobile screens); and 4) improving and/or reproducing the initial AR app using the OpenCV (replacing the original EasyAR software development kit) to sequence the learning materials upon request once a component is recognized. **Results:** This updated AR app with enriched virtual lab modules was tested and validated by the class lecturer and graduate students who had already taken this HVAC class. Their feedback showed that the AR tool would allow students to learn at their own pace while the instructor is not face-to-face with them, and the results revealed that the tool enhanced student's practical skills especially when they are sheltered at their homes without accessing a physical lab. This AR-based supplementary learning tool is ready for use in the HVAC class for this coming spring semester, and the app's effectiveness will be more comprehensively evaluated once students in the class adopt the tool. **Conclusion:** A well-designed AR learning app will effectively guide students to perform hands-on experiments related to the HVAC course. The alternative pedagogy through AR technology also provides an efficient way to deliver practical experience online, especially when on-campus lab resources are limited or people are sheltered at home during natural disasters like the COVID-19 pandemic.

Key Words: Covid-19, Engineering education, Experiential learning, Online education, Augmented reality, HVAC course.

1. Background

COVID-19 spread quickly around the world after the end of 2019, and several control measures were regulated by the United States governments, such as shelter-in-place orders, social distance, and quarantine. Covid-19 and the control measures have affected the entire society. For example, most students had to attend online classes instead of face-to-face classes, while the hand-on laboratory and field experiments are not convenient to be conducted online by students. However, these laboratory and experiments are a key aspect of engineering education given that they can strengthen the connection between academic and industry and help students understand the fundamentals of engineering. A solution may be found with the recent advances in Augmented Reality (AR) technology that is widely employed in education setting (Akçayır & Akçayır, 2017). Augmented reality (AR) is an interactive experience that combines a real-world environment with computer-generated elements in the real world (Azuma et al., 2001; Wikipedia, 2021). The AR system has three features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects.

AR was first employed as a training tool for airline and Air Force pilots during the early 1900s (Akçayır & Akçayır, 2017). Since then, it has been widely used in every school level from K-12 (Chen & Tsai, 2012; Chiang, Yang, & Hwang, 2014; Kerawalla, Luckin, Seljeflot, & Woolard, 2006) to the university (Ferrer-Torregrosa, Torralba, Jimenez, García, & Barcia, 2015; Munoz-Cristobal et al., 2014). This is because AR can be accessed with different technologies such as table PCs, mobiles, and tablets. With an increasing number of mobile device owners, AR is available to more people. Furthermore, AR applications increased dramatically because the mobile device is simpler and more portable (Martin et al., 2011). Compared to other technologies, AR has several advantages. Firstly, AR improves interactions between students and their student peers (Kamarainen et al., 2013), between students and the materials (Kamarainen et al., 2013), and between students and teachers (Zarraonandia, Aedo, Díaz, & Montero, 2013). Secondly, AR has a positive effect on students' learning attitudes (Cai, Wang, & Chiang, 2014). AR can also motivate students (Kamarainen et al., 2013). Despite the great progress of AR technology in many fields, it has a limitation in the engineering disciplines. For example, there are no mobile AR apps regarding the comprehensive education of building energy systems.

The building sector consumes the largest end energy in the United States that accounts for 39% of the total energy used (U.S. EIA, 2020). Therefore, training engineers to enhance building energy efficiency and sustainability of buildings is very important. Moreover, although North Dakota has the largest residential and commercial building energy consumption per capita (ranking 1st and 2nd in the nation, respectively (Yang et al., 2020)), there is no comprehensive academic program related to building energy systems in this state, thus limiting the production of local professional engineers in the field of building energy systems. Therefore, an increase in courses related to building energy systems may satisfy the demand of local professional engineers. As AR technology makes students access the online course simpler through mobile devices, it may help the state train more professional engineers through opening more online courses related to building energy systems. However, as mentioned above, there are no mobile

AR apps regarding the comprehensive education of building energy systems. This paper enriches our initial learning app about HVAC through an AR environment.

2. Purpose/Hypothesis

This paper presents a library of virtual laboratory modules expanded and enriched from our initial learning app through an AR environment, where virtual objects (augmented components) are superimposed onto a real learning setting during online lecture instruction. Specifically, to facilitate students' gaining practical skills, a library of virtual objects was established for the main physical components or systems related to the undergraduate HVAC class to allow students to be immersed in an augmented learning reality representing the real physical world.

3. Design/Method

This research will 1) include all 2D figures of the main HVAC components in an HVAC course; 2) refine these components' 3D models with learning materials (e.g., concept and evaluation); 3) improve the AR method to recognize each component's figures or pictures from any learning documents (e.g., printed lecture ppt notes and textbook, documents shown on computer or mobile screens); and 4) improve and/or reproduce the initial AR app using the OpenCV (replacing the original EasyAR software development kit) to sequence the learning materials upon request once a component is recognized.

Recognizing figures and images presented in the book or lecture notes plays an important role in the mobile AR app. After recognizing the figures, the 3D model will be rendered in this app. Two software programs are implemented in this study: EasyAR and OpenCV (Open Source Computer Vision). EasyAR is a commercial tool and provides a flexible dataflow-oriental component-based define (API). OpenCV is a library of programming functions mainly aimed at real-time computer vision. There are a lot of algorithms required for feature detection and description, including Harris Corner Detection, Scale Invariant Feature Transform (SIFT), Speeded-Up Robust Features (SURF), Features from Accelerated Segment Test (FAST), and Binary Robust Independent Elementary Features (BRIEF) (Wikipedia, 2021). Among the algorithms, SIFT and SURF usually return the best result, while the FAST fits the real-time application better. Oriented FAST and Rotated BRIEF (ORB), as an alternative algorithm to SIFT and SURF, has a FAST detector and BRIEF descriptor. Therefore, this paper uses the ORB algorithm as the feature detection and description because it has a good speed and quality detection. Both tools work across platforms such as Android and IOS systems.

3.1 Object's 3D model development

In this study, AutoCAD software is employed to develop a three-dimensional (3D) model of the HVAC components such as economizers, evaporation coils, heat exchanges, etc. According to the formed components, some devices of HVAC system are composed such as Air Handling

Units (AHU). This 3D model helps the students understand the concept, mechanism, calculation, and evaluation easier, compared to the 2D models shown in the textbook. After the 3D model is developed with the AutoCAD software, animations are added into the model, which makes the students grasp the HVAC system in real-life HVAC applications. Below is an example of the 3D model's animation.

The components of an AHU developed with the AutoCAD software are shown in Figure 1, which includes exhaust fan, temperature/pressure sensor, mixing box, grille, dampers, filters, cooling/heating coil, and supply fan.

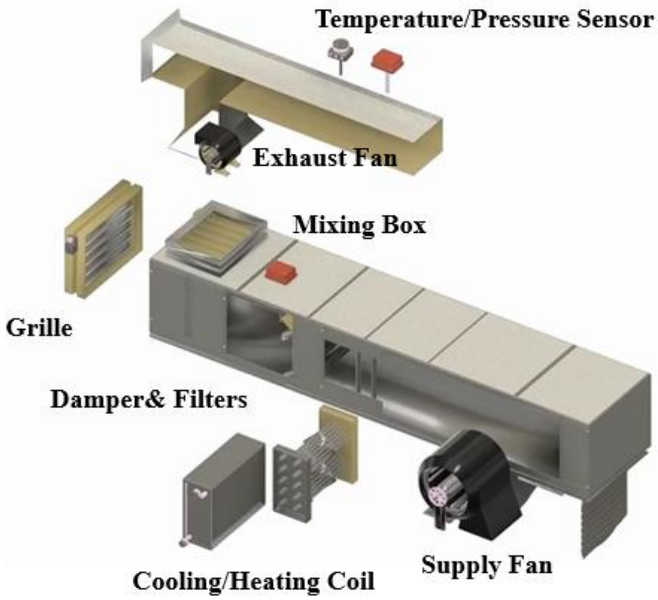

Figure 1. AHU's components

Figure 2 shows the components of an AHU's 3D model with the airflow direction. In this figure, the red, blue, and yellow lines represent the return air from the building, fresh outdoor air, and supply air (or mixing air) to the building, respectively. This model provides the learner with the right procedures for designing and improving an AHU (e.g. the concepts and calculation steps). Finally, the 3D model animation is added into the previous 3D model. This model simulates the real AHU device with its visual aspects. The students not only can learn how each individual AHU component works, but also learn how the entire device of AHU works.

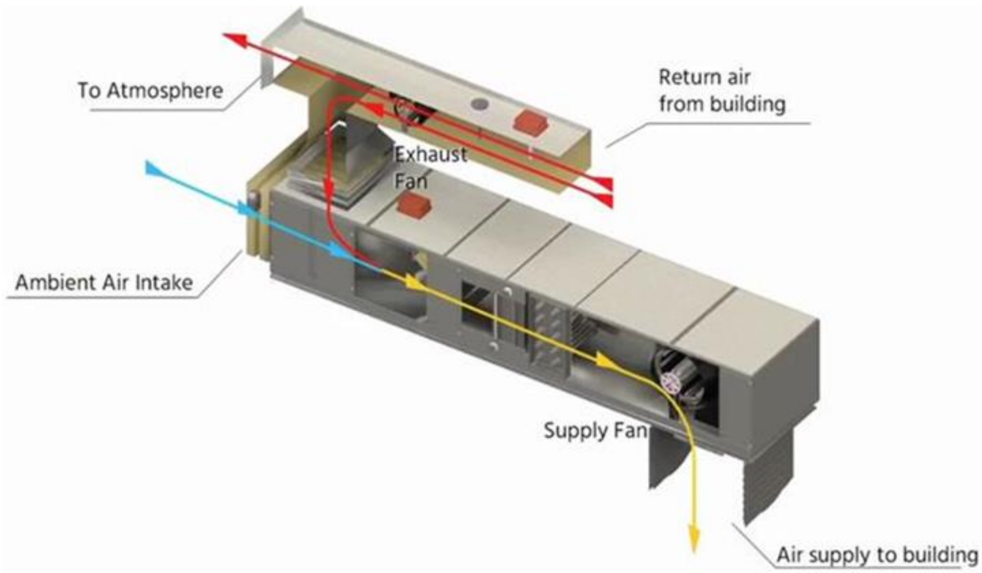

Figure 2. Air handling unit's 3D model and air circulation route

3.2 AR application development

Unity is used in this study to create the mobile app because it is most suitable for the game development. An app can be developed within Unity in a short time and with low costs.

Figures 3 to 8 show the main procedures to create the mobile app by Unity. The first step is to import the project into the Unity hub. After that, Figure 4 will be shown on the screen, where the name panel of "SampleObject" under the Hierarchy tab has three components: CanvasObject which contains a textbox and a button to display the mode's name, CanvasScreen which contains the user interface, and CanvasVideo which contains a video player to display the video/animation. The second step is to bind the 3D model and image for recognition. In this step, the 3D model, image, and video files are imported into the Prefebs folder, StreamingAssets folder and Videos folder, respectively. After importing the files, the model ("air-handler-assem" in this case) will be dragged from Prefebs to the Object as shown in Figure 6. Then, the model will be linked with the image and video. The third step is to run and test the program. If the program works well, the real application will be generated.

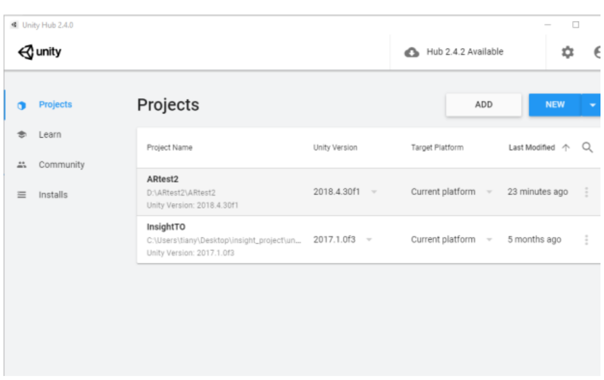

Figure 3. Importing the project into Unity

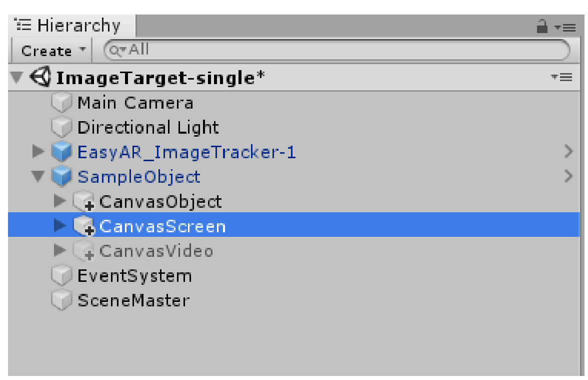

Figure 4. SampleObject under hierarchy

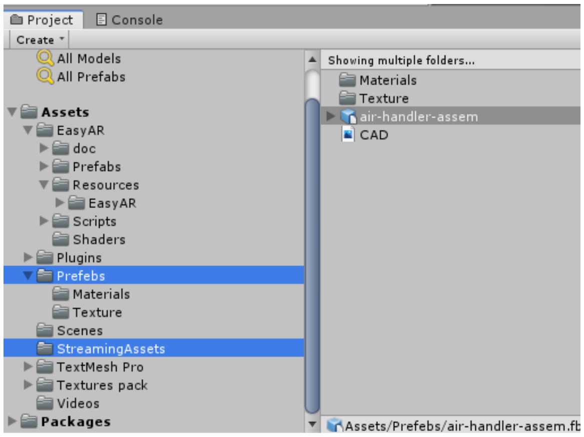

Figure 5 Importing the 3D model, image, and video

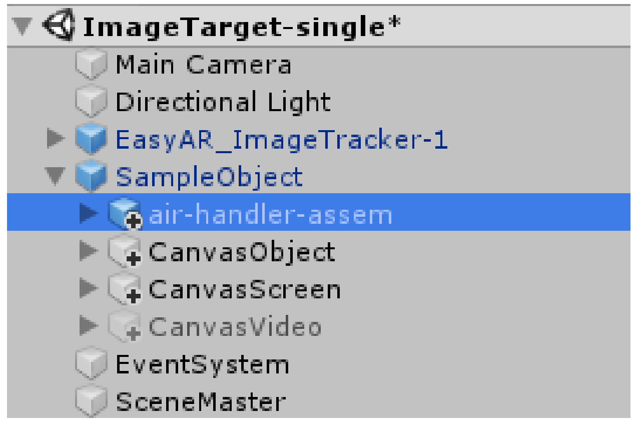

Figure 6. Air handle assemble model

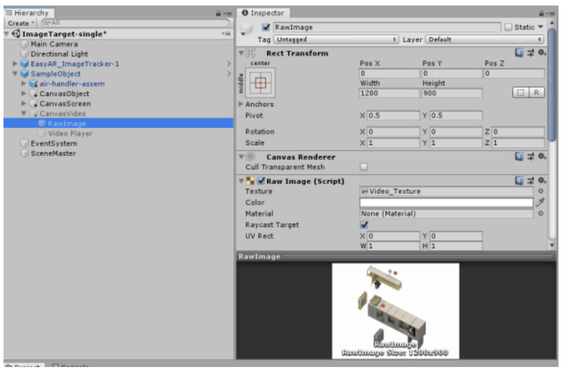

Figure 7. Air handler assemble model linked with video

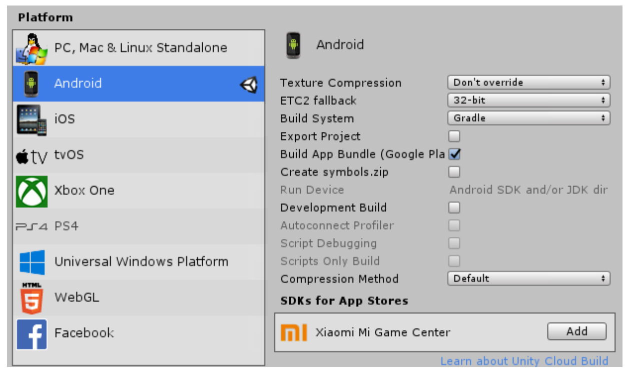

Figure 8. Generating the real application

The mobile app for the HVAC course developed with the Unity is shown in Figure 9 with three basic functions: 1) the name of object shown on its top after clicking the blue reorganization, 2) the text information shown after clicking the message button, and 3) a related video playing once a button is clicked.

A name panel is located at the top of a captured object image on the app screen. Once the button of this panel is clicked, the camera will be turned on and start taking the picture. After the image is captured, the app will start to recognize it using OpenCV and/or EasyAR. Then the corresponding 3D models will be trigged. The learners will watch the components of the HVAC system and how they work. This will allow students to gain online practical experience regarding the HVAC components, especially when physical lab resources are unavailable to students or even when students are sheltered at home during the COVID-19 pandemic.

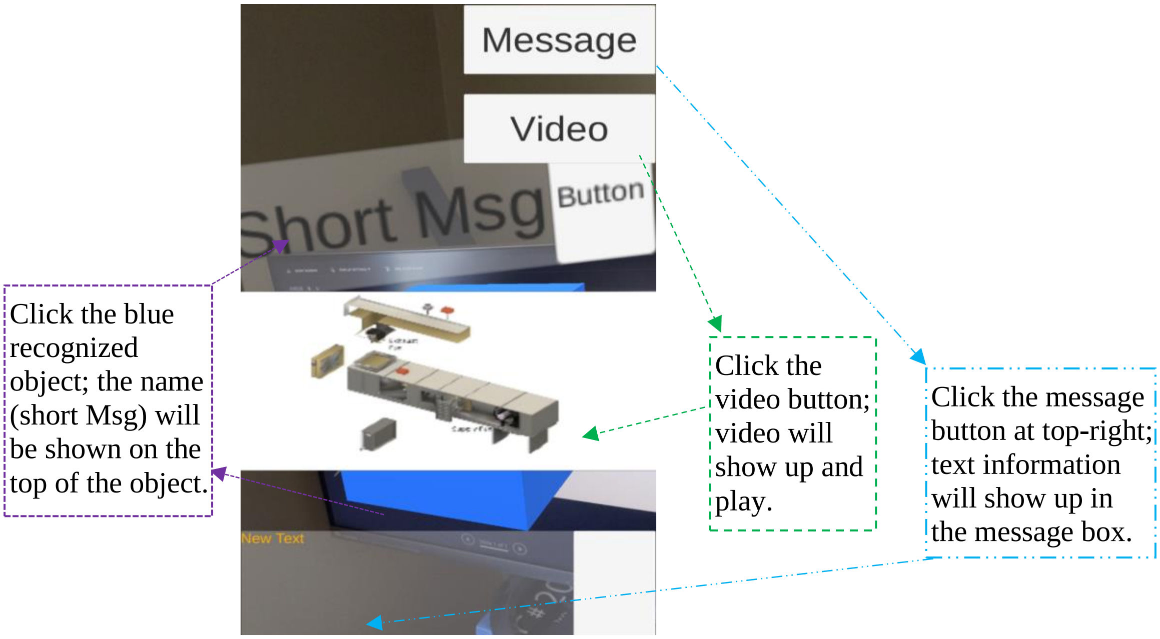

Figure 9. Usage of the app's three functions

3.3 Assessment

In this study, the experiments will be employed for assessing the students' learning outcomes through the AR learning system. The participants are students enrolling in the HVAC course at North Dakota State University during this spring semester. The students in this course can select the online or face-to-face class settings based on their requirement. The assessment includes two stages: 1) evaluation of learning outcome, 2) evaluation through questionnaire.

At the first stage, all students at both the online and face-to-face class settings are asked to use AR mobile app. Then, their learning outcomes or scores from the related homework, quizzes, tests will be compared to those of their peer students in the last year HVAC class without the AR app implemented. It is assumed that the background and class entry knowledge are the same for students among different years, and the class assessments (homework, quizzes, and tests) between the two years are similar for a fair comparison. At the end of the semester, homework, quizzes, midterm test and final test will be collected to analyze the result. A t-test will be used to determine whether there is a significant difference between the students using mobile AR app and those without the app.

At the second stage, the students are asked to do the questionnaire developed by (Jou & Wang, 2013). Five basic questions are implemented in this questionnaire: learning interest, motivation, learning accomplished, learning attitude, and tutoring of mobile AR app. The questionnaires will be conducted by all the students who used the mobile AR app at the end of semester. The research will collect the data of the questionnaires as shown in Table 1 and conduct the t-test to determine if mobile AR app for HVAC course has a positive effect on the student's skill. The results of the assessments will be completed at the end of the spring semester.

Table 1. Selected questionnaire from IMMS (Keller, 2009)

Questions	Overall grade (1-5)
There is something interesting in the mobile app for the HVAC course that got my attention.	
I can use the mobile app to recognize the HVAC component easier.	
After watching the video of the tutoring of the mobile AR app for the HVAC course, I felt confident that I could control the app easier.	
The mobile app is eye catching.	
When I first looked at the mobile app, I had the impression that it would be easy for me.	
I enjoyed studying from the mobile app more as compared to the traditional face-to-face class.	
I am able to figure out how the HVAC works through the mobile app easily.	
The mobile app for the HVAC course has things that stimulated my curiosity.	
I can connect what I learned from the mobile app with the real world	
The content from the mobile app for the HVAC course is useful to me	
I am glad to study the HVAC course through the HVAC app.	

4. Results and discussion

In this paper, all the main components in an HVAC course have been added into virtual 3D modules as well as implemented into the app this spring semester. This updated AR app with enriched virtual lab modules is ready for use in the HVAC class and will be tested and validated by undergraduate students enrolled in the class. Then, the app's effectiveness will be more comprehensively evaluated once students in the class adopt the tool. In order to further evaluate the mobile app, the assessment of the mobile app for the HVAC course has been designed, which includes two stages: evaluation of learning outcome and evaluation through a questionnaire. The first stage is to evaluate the learning outcomes using homework, quizzes, or tests, while the other stage is to conduct and evaluate questionnaires. After the data are collected, t-test will be conducted to determine whether the mobile app of the HVAC course has a positive effect on the HVAC class for both the online and face-to-face class settings. The results of the assessment will be provided when they are available.

5. Conclusion

This paper presents a library of virtual laboratory modules expanded and enriched from our initial learning app through an Augmented Reality (AR) environment, where virtual objects (augmented components) are superimposed onto a real learning setting during online lecture instruction. Moreover, the updated AR app with enriched virtual lab modules will be evaluated by the students enrolling in the HVAC course, which will in turn help this app satisfy the requirements of the students. A well-designed AR learning app will effectively strengthen the connection between academics and industry and help students understand the fundamentals of HVAC engineering. AR technology also provides an efficient way to deliver practical experience online, especially when on-campus lab resources are limited or people are sheltered at home during natural disasters like the COVID-19 pandemic.

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