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Abstract

Background: The ongoing COVID-19 pandemic has recently resulted in an emergent shift of traditional instruction to (presumably temporary) online delivery, and many students were not able to participate in practical activities (e.g., laboratory experiments) due to inaccessible or unavailable "brick and mortar" laboratories. **Purpose:** This *works-in-progress* paper developed a multimedia learning platform with virtual laboratory modules 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 were 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:** This proceeds in the following steps: 1) selecting a set of common HVAC components in the HVAC course; 2) developing an AR method to recognize each component's figures or pictures from any learning documents (e.g., printed lecture ppt notes and textbook, and documents shown on computer or mobile screens); 3) establishing components' 3D models with learning materials (e.g., concept and evaluation); 4) developing an AR app sequencing the learning materials upon request once an component is recognized; and 5) evaluating the app's effectiveness. **Results:** This *works-in-progress* developed an initial AR app for an air handling unit (one main HAVC component), and the AR-based supplementary learning tool was tested and validated by graduate students who have already taken this HVAC class before. Their feedback showed that the AR tool would allow them to learn at their own pace while the instructor is not face-to-face with them, and the results revealed that the tool enhanced their practical skills especially when they are sheltered at their homes without accessing a lab or field trip. **Conclusion:** A well-designed AR learning app will effectively guide students to perform hands-on experiments related to the HVAC course and other STEM laboratory courses. 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

1. Background

Hands-on laboratory experience plays a critical role in students' learning of engineering subjects, enhancing their practical skills such as conceptual understanding and problems solving skills. However, the ongoing coronavirus pandemic has recently resulted in the unprecedented disruption of the entire society and education system in the United States. With over seven million confirmed cases and 200,000 deaths reported by September 26, 2020 (CDC, 2020), school closures resulting from shelter-in-place orders and social distancing (or quarantine) measures nationwide have been enforced as a non-pharmaceutical measure to minimize the virus spread and prevent illness and death. To maintain teaching and learning, traditional face-to-face instruction shifted overnight to (presumably temporary) online delivery. However, before evaluating the readiness, feasibility and effectiveness of this emergent switch, higher education witnessed it hard or impossible to deliver practical activities online (Langford & Damasa, 2020) such as hands-on experiments or field trips, especially in science and engineering. A solution may be found with the recent advances in Augmented Reality (AR) technology that overlays virtual objects (augmented components) onto the real world (Azuma et al., 2001; Akçayır, 2017).

AR technology now can be used with computers or mobile devices, no longer requiring expensive hardware such as head-mounted displays (Caudell & Mizell, 1992), and it is used today in every school level from K-12 (Chang, et al., 2015; Chen & Tsai, 2012) to the university (Muñoz-Cristóbal et al., 2015) since its first introduction as a training tool during the 1990s (Lu & Liu, 2015). AR advantages in educational settings include the enhancement of: learning motivation (Kamarainen et al., 2013), achievement (Muñoz-Cristóbal et al., 2015; Hsiao, et al., 2012), and satisfaction (Zarraonandia, et al., 2013; Stefanou, et al., 2013); learner's positive attitude (Panadero, 2017); and interactions of student-student (Zimmerman, 1990), student-material (Da Rocha Seixas, et al., 2016), and student-teacher (U.S. EIA, 2017). The mobile AR apps are very cost-effective and easy to access, i.e., with limited hardware (a mobile device such as tablet) and an internet connection, and can maximize students' utilization of fragmental study time. However, there are no mobile AR apps regarding the comprehensive education of building energy systems.

In the United States, buildings (as the biggest energy end-use sector) consumed over 39 quadrillion British thermal units in 2019 (U.S. EIA, 2020), that accounts for 39% of the total energy used and more than 34% of the total carbon dioxide emissions. In order to train future scientists and engineers to improve the health, energy efficiency, and sustainability of buildings, hands-on laboratories play a crucial role in their undergraduate education. Geographically, North Dakota has not only the highest building energy consumption per capita in its local region, but its residential building energy consumption per capita (105.1 MM Btu in 2014) and its commercial one (111.4 MM Btu in 2014) rank 1st and 2nd in the nation, respectively. However, there is no comprehensive academic program (e.g., Architectural Engineering) dedicated entirely to buildings in North Dakota, and the lack of college level coursework related to building energy systems limits the production of local skilled professionals to meet the growing workforce demand, given the building boom that has swept the state—it's estimated that 90,000 new residents moved to North Dakota between 2010 and 2019 (Wiki, 2020). Therefore, a viable solution may be found with a multimedia learning platform with a comprehensive curriculum related to building energy systems.

2. Purpose/Hypothesis

To address aforementioned issues related to undergraduate education in building energy systems, especially in the vicinity of North Dakota, this research will, therefore, use AR technique in creating a mobile app to provide a multimedia learning platform to enhance the learners' practical experimental experience for the undergraduate HVAC (Heating, Ventilating, and Air-conditioning) class, a core course related to building energy systems. With the mobile AR, students can use a mobile device such as a table or smartphone to visualize and interact with a scene that contains both physical world and visual objects. The main research questions of this *in-progress work* are: 1) Can a mobile AR multimedia learning app with 3D virtual modules be developed for the common HVAC components covered in this HVAC course? 2) Is the initial version of the mobile AR app effective to facilitate students' practical experience and to enhance their practical skills.

3. Design/Method

This research will 1) first select a set of common HVAC components covered in this HVAC course, with the air handling unit and the air conditioner taken as an example in this paper; 2) develop an AR method to recognize each component's figures or pictures from any learning documents (e.g., printed lecture ppt notes and textbook, and documents shown on computer or mobile screens); 3) develop each component's 3D model with learning materials (e.g., concept, mechanism, calculation, and evaluation); 4) develop an AR app sequencing each component's learning materials upon request once the component is recognized; and 5) evaluate the effectiveness of the AR app by participating students.

The critical phase for this AR application is recognizing figures/pictures in printed learning documents (or those shown on screens), and then rendering a virtual 3D reality on the object. The methodology was implemented using two software development kits (SDKs) in this project: EasyAR and OpenCV (Open Source Computer Vision). EasyAR is a commercial tool, but has many built functions to facilitate the AR development; while OpenCV is an open-source tool for image processing, and is highly customizable with a collection of available algorithms, which is especially suitable for developing HVAC application. Both tools work across platforms such as Android and IOS systems.

3.1 Object recognition

We used feature detection and matching method to find the target picture through a camera, and Figure 1 shows the logic for the object recognition using the OpenCV.

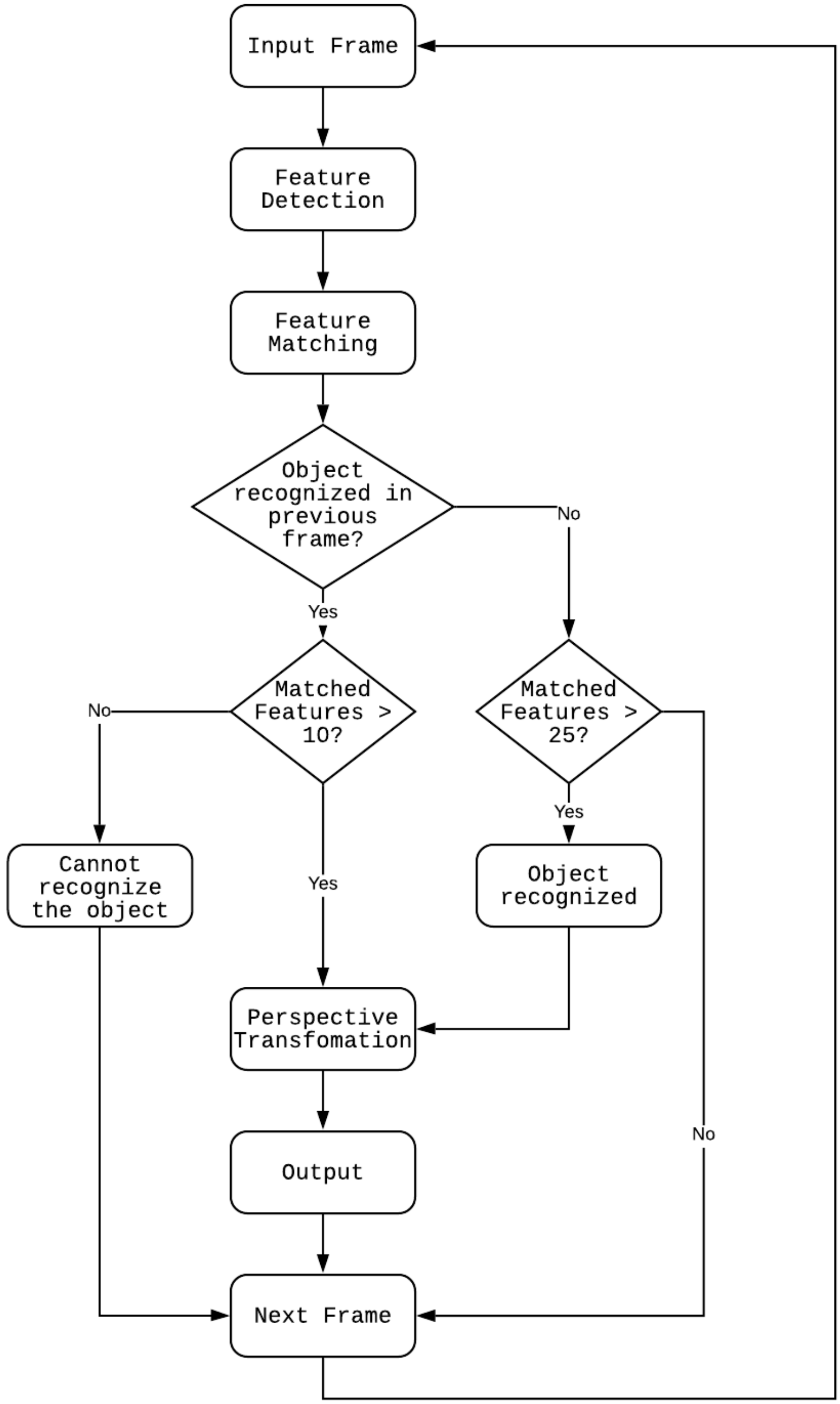

Figure 1. Object recognition using OpenCV

In the OpenCV library, there are seven feature detection techniques, including Haris corner detection, Shi-Tomasi corner detection, SIFT (Scale-Invariant Feature Transform), SURF (Speeded-Up Robust Features), FAST algorithm for corner detection, BRIEF (Binary Robust Independent Elementary Features), and ORB (Oriented FAST and Rotated BRIEF). In general, SIFT and SURF usually return the best result, and the FAST fits real-time application better. The ORB algorithm involves FAST detector and BRIEF descriptor, and usually is considered as an alternative to SIFT and SURF. The ORB algorithm has been chosen as the detection algorithm in this project due to its good speed and quality detection. Figure 2 shows a detection example for the outside unit of a residential air conditioner.

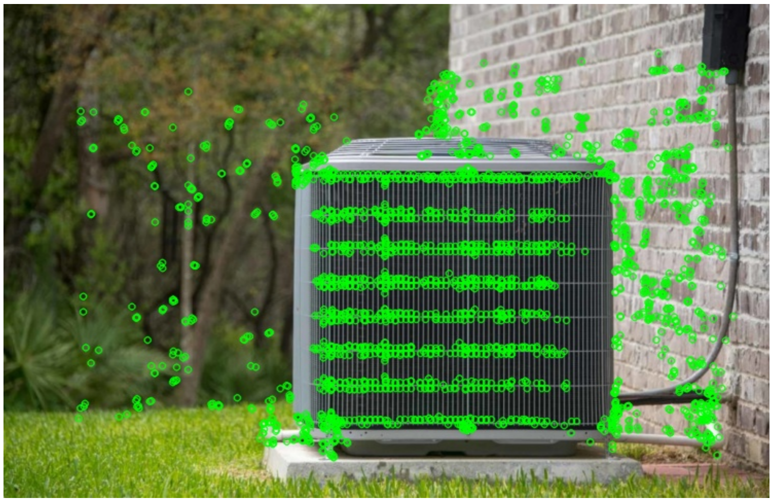

Figure 2. ORB detects 2500 features on original image

Two matchers are also supported by the OpenCV library: Brute-Force based matcher and FLANN (Fast Library for Approximate Nearest Neighbors) based matcher. The two matchers were tested for this project. Compared to the FLANN based matcher, the Brute-Force matcher runs more slowly especially on large dataset although it can guarantee finding the best match. Thus, the FLANN algorithm was chosen as the matcher in this project because it has both high enough matching accuracy and good speed performance, as shown in Figure 3.

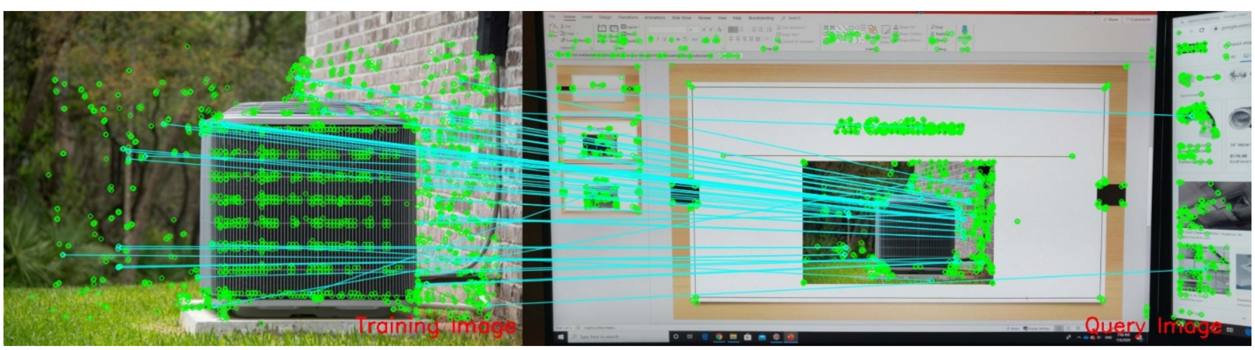

Figure 3. Match result (61 matches)

To further improve the whole recognition performance, an adjustment was made as follows: the number of features detected from the query image remains 2500, while that on the training image reduced to 500. Thus, only 2500 features points with 500 feature points, rather than 2500 feature points with another 2500 feature points, need to be matched for this updated process. As showed in Figure 4, the matching accuracy remained the same with a faster matching speed.

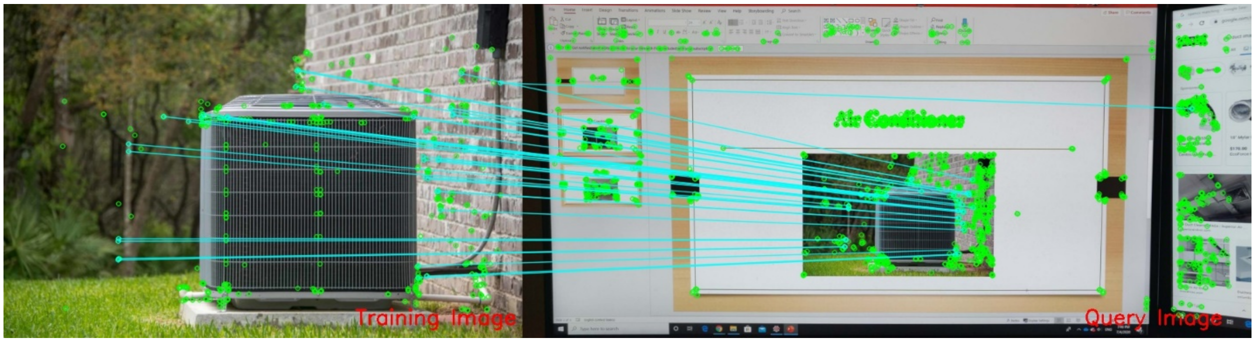

Figure 4. Match result (40 matches)

Once the feature points are matched, they need to be transformed to the object's actual shape and pose so that the object can be found on the captured image. Thus, the perspective transformation functions supported by the OpenCV were used to project the actual shape and pose of the object on the camera, as exemplified in Figure 5.

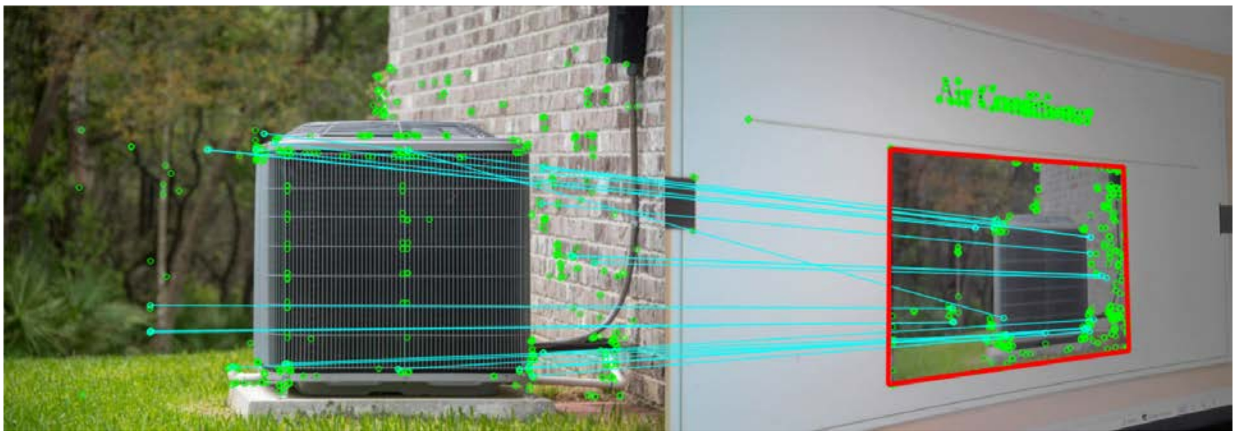

Figure 5. Transformation result from angled picture

In a real AR application, students use a camera in a mobile device to take images frame by frame (i.e., creating a video) from learning materials (e.g., lecture notes, screens in a classroom), and each image frame input is considered as one single captured image during the object recognition. For example, for a captured video input with a 30 fps (frames per second), the object recognition program will process 30 consecutive images per second. Then, a captured image is considered as a recognized object once the number of matched features between the target image and captured image is over a threshold value. Normally, the distance between the camera and the learning materials (e.g., lecture notes) is assumed to be within two feet, and this benchmark value is set as 25 for our application.

However, an unstable recognition (e.g., false-rejection) may occur in some cases where the actual matched features are around 25. For example, during a specific range of distance between the camera and learning materials, a current frame captured image has 25 matched features, but the next frame image may be 24 perhaps because the distance slightly increases due to the camera position change, or vice versa. The frequent back-and-forth (i.e., "accept" and "reject") recognition results make users feel uncomfortable. To solve this issue, two different threshold values, instead of one single value, were adopted in this project. The first threshold value of 25 is for an initial recognition, and the second value of 10 is applied for any frame image if its previous frame image is recognized. The threshold value will be reset to be 25 once a captured frame image is found not to be a recognized object. Thus, the object recognition keeps tracking a target image far away from the camera once the target image is recognized, unless the camera is too far away from the target image to recognize a captured frame image (in this case, it is required to move the camera closer to the target image for a new object recognition). The whole process of object recognition is schematized in Figure 1.

3.2 Object's 3D model development

For each selected HVAC component, AutoCAD was employed to develop its 3D model which enables the object's learning materials with respect to its concept, mechanism, calculation, and evaluation. Animations were also added to the 3D model for learners to better understand the component's real 3D structure, mechanism and operation with a corresponding air circulation route in real-life HVAC applications. Compared to 2D schematics, the 3D model can demonstrate the full picture of a real HVAC component, including its shape, size, even surface material, pose with a rotation at different zooms.

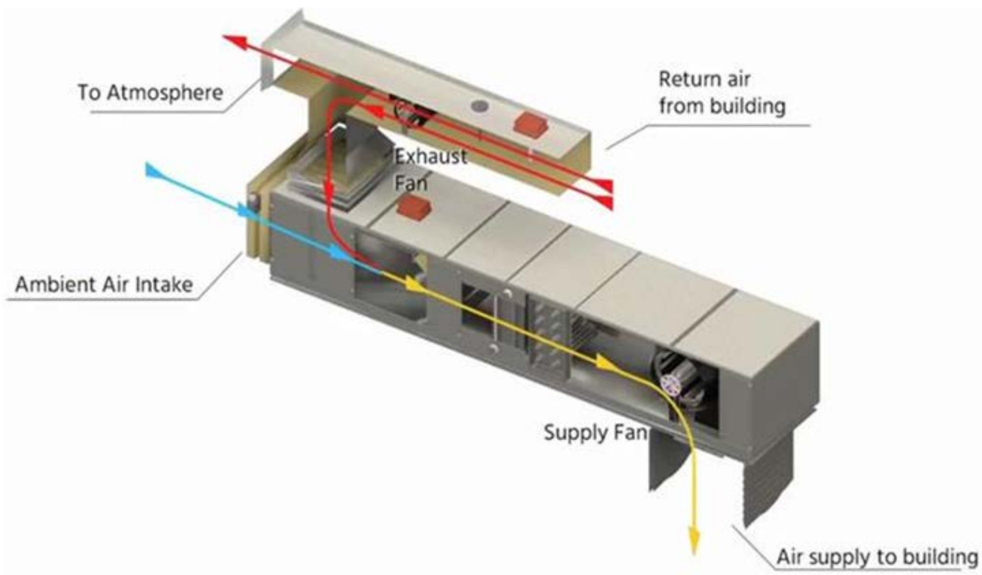

Figure 6. Air handling unit's 3D model and air circulation route

Figure 6 shows the 3D model of an air handling unit (AHU) with its airflow direction as an example, where 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. The return air is partially introduced to the air recirculation through the mixing box, while the rest of the air is rejected to the atmosphere directly. The mixing of return air with the fresh air allows the return air to participate the air recirculation mixing with the ambient air. Finally, the mixing air is processed in AHU and then blown into the building by the supply fan.

The model's animations are enabled by the independent, self-contained 3D models of the AHU's sub-components (in Figure 7) such as exhaust fan, temperature/pressure sensor, mixing box, grille, dampers, filters, cooling/heating coil, and supply fan. Supply/exhaust fans allow the air flow in\out of the circulation. To meet the heating/cooling load of indoor environment, the air is processed by the heating\cooling coils before the supply fan. Dampers in this system are further employed to control the air flow rate by changing their opening position to meet the indoor comfort requirement (e.g., by monitoring the indoor CO_2 level). Filter and grille are also significant components to ensure the air's quality and cleanliness. A grille is normally at front on the inlet/outlet of duct housing to prevent pollutant or even the wildlife. Filters (observed as panel or bag types) are generally located after the damper inside the ductwork to capture small-sized pollutant (like dust).

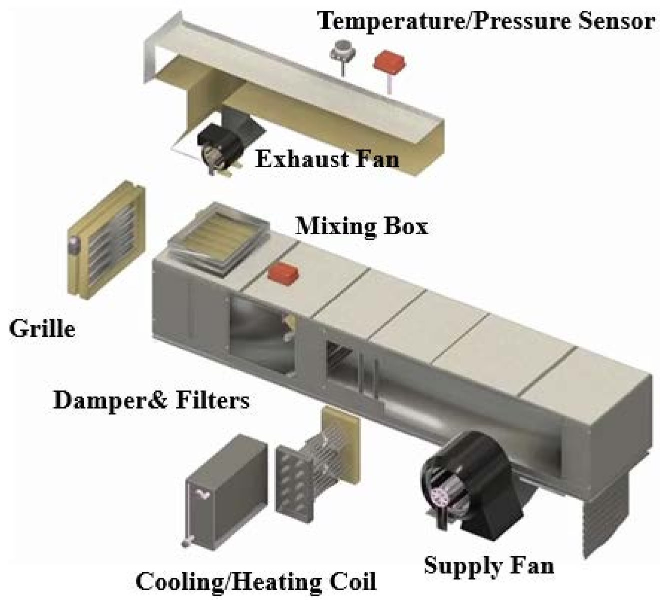

Figure 7. AHU's expanded models

3.3 AR application development

Then, EasyAR SDK 4.0 with Unity was used for coding and testing to develop the initial version of the AR app, given that its easy-to-use and built-in functions allow a faster app development and its compatibility with Unity (a popular engine to create AR games) enables more AR features for the app. Figure 8 shows three basic functions of the initial app: 1) popping up the name of a recognized object on the top of its captured image, 2) presenting the text instructional materials in three tags (i.e., concept, mechanism/calculation, and evaluation) for an object, and 3) playing a related video once a button is clicked.

To facilitate the app users in reading the object's name, a name panel is designed on the top of a captured object image and always faces up to the camera no matter where the mobile devices (e.g., phones) are located. The 3D models with learning materials will be trigged once an object image is recognized. Users can easily define a recognizable image for an object. For example, an instructor can configure any image for an HVAC component, and share the images with students. Multiple images can be configured for each different 3D object. Then, students can access the HVAC component's vivid virtual 3D multimedia learning materials in the app once they scan the images (e.g., on the hard-copy or electronic notes as well as textbooks) using mobile devices. This will allow students gain online practical experience regarding the HVAC component especially when physical lab and fieldwork resources are unavailable to students or even when students are sheltered at homes during the COVID-19 pandemic.

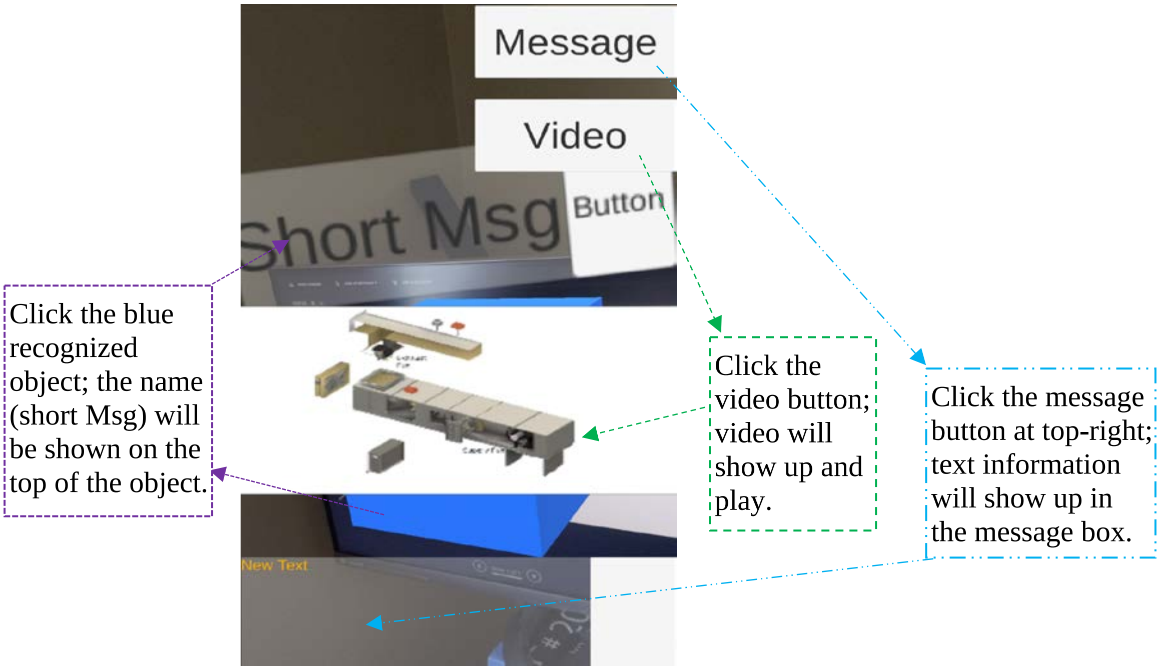

Figure 8. Usage of the app's three functions

Further, there are three tags to present the instructional materials of a recognized object image in the text format, and the animations of text information are provided around the 3D virtual model to facilitate students in effectively and efficiently learning the materials regarding a recognized object. Also, instructional video (trigged by clicking a button) are available to provide visual content as an alternative to the textual learning materials, given that many learners especially younger people indicate a strong preference for videos.

4. Results and discussion

This in-progress work studied two main HVAC components: the outside unit (i.e., condenser) of a residential air conditioner and the AHU of a commercial HVAC system. Given that the undergraduate HVAC course is typically offered in spring semesters, therefore, this AR app has been initially evaluated by the course instructor and two graduate students who have already taken the HVAC course, before it is implemented in the HVAC course and tested by undergraduate students. The evaluators have achieved the consensus: the AR app will effectively facilitate students in gaining practical experience in the HVAC field, and it can be seamlessly integrated into the lecture of HVAC-related courses, especially when the HVAC lab resources are unavailable or even students are sheltered at home during the COVID-19 pandemic.

Given that only a limited number of 3D HVAC component modules (e.g., an air handling unit with animations) have been developed for the initial AR app, a more comprehensive evaluation of the AR multimedia leaning app needs developing more virtual 3D modules of common HVAC components and systems as well as implementing the app in the HVAC course in next spring semester. Thus, in the near future, we will move forward the in-progress work as follows: 1) developing rich 3D models and related learning materials for more HVAC components; 2) improving the whole app in the OpenCV platform (some functions and components coded in the EasyAR platform will be reproduced using OpenCV), given that EasyAR is not an open-source tool and the AR app's broader adoption may be limited; 3) implement the AR app in the HVAC course in spring semesters and evaluate the efficacy of the new instructional method in engineering education.

5. Conclusion

A well-designed AR learning app will effectively guide students to perform hands-on experiments related to the HVAC course and other STEM laboratory courses. 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.

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