Enhancing Size Perception with True-Size Viewing CAD plug-in and Cloud-enabled AR APP

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Abstract. Correct size perception plays an essential role in the design, while viewing the virtual model at its true size provides good intuitiveness. However, most mainstream 3D CAD software has no true-size display function. This paper developed a True size viewing platform consisting of a CAD plug-in and a marker-based AR APP. The former can display the virtual model at its true size on the screen, and a user study confirms the plug-in can improve size perception. The latter renders 3D models retrieved from the cloud at their true size on the smartphone, making the viewing process more natural and efficient. Users can skip the tedious operations of the traditional AR APP and focus more on the design. The AR APP can be utilized by several users simultaneously and achieve the effect of viewing the same object from different perspectives. The plug-in fills the gap of missing true-size display function in current 3D CAD software, while the AR APP reduces complexity significantly in the preparations for viewing in AR.

1 INTRODUCTION

CAD brings a revolution into the design and engineering field. The appearance of CAD enables designers and engineers to get rid of the drawing board and restricted size. The graphics in the CAD can be easily modified, while the scale can be free changed. However, compared with manual sketching or viewing the drawing on paper at the scale of 1:1, it is difficult to have an intuitive understanding of the part size when designing and viewing models in CAD software since the displayed size usually differs from its true size[2]. Different displayed size causes different feeling and understanding about the same part. The reason for this is the inaccurate size perceiving process.

Size perception refers to the complex cognitive behavior of interpreting the spatial geometry magnitude of objects[6][12]. For a familiar object with a well-known size, its perceived size tends to remain identical regardless of the varying visual angle led by the changing distance[10]. This phenomenon is known as size constancy[13]. The familiar object can be used as a reference to

perceive the size of the unfamiliar object. However, the part in the CAD is usually of low familiarity and presented without any familiar object, so its size will be mainly perceived based on the perceived target distance and the visual angle. When observing a close object, just like the monitor in front of the viewer, the convergence which happens when two eyeballs focus on the same object plays an important role among all cues[4][11]. The displaying method in the 3D CAD software uses the 2D image of a virtual camera targeting the model located at a virtual distance. The viewer perceives the displayed size instead of the true size, while the perceived target distance is the distance between the viewer's eyes and the monitor. Even when the virtual model is placed in a virtual environment identical to the real scene, it is also perceived to be smaller than the real object, although the retinal size is the same. The CAD Window will show all the Camera Range, and the ratio of CAD Window Size to the Displayed Size equals the one of Max Camera Range to True Size. Figure 1 is given below to illustrate the display method in the 3D CAD more clearly.
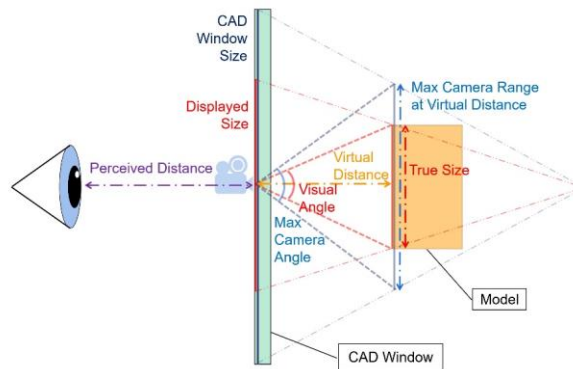

Figure 1: Size Perception when viewing a model displayed on the screen.

The difference between the displayed and true sizes usually leads to an inaccurate object size estimation. Measuring the true size with the measuring function in CAD software and using a ruler as a reference to imagine the part can alleviate this problem. Still, it will cause the suspension and break the continuity of viewing progress. Additionally, measuring and imagination will be difficult when the model has a complicated structure or curved surface. There is no 1:1 true-size display function that enables the monitor to display the object at its true size in most mainstream 3D CAD software. Therefore, manually zooming is needed to display the object at its true size needs to be conducted with a ruler placed on the monitor. This operation is tedious and time-consuming, which prevents the user from doing so. In this paper, A CAD plug-in is developed to automate the zoom operation to achieve the effect of true-size displaying to free the user from repeated work.

Planar true size viewing on the monitor has its limitations. 1)it is not efficient enough since it is necessary to switch the viewing direction to observe the whole model. 2)When the object is larger than the monitor, it cannot be fully viewed. 3)The object cannot be placed in an environment surrounded by other objects as the reference. With the development of VR/AR technologies, the virtual environment is widely used in many fields such as industrial training, education, and design enhancement. Through the headset or smart devices, users are able to sense the virtual object in a more immersive way than the planar monitor. Additionally, a study conducted by FANIKA LUKAČEVIĆ et al. indicates that engineering students had more accurate size perception in the immersive virtual environment (such as AR/VR) than in traditional virtual environments (such as a 2D screen)[8]. AR can render the virtual object in the real world. Thus, compared to VR, users can have more intuitive and natural perceptions. Therefore, a Cloud-enabled mobile Augmented Reality App is also developed to enhance the size perception.

There is less research on true-size display in academia, especially in CAD. While in practice, plug-ins are available on the internet, sharing the idea of displaying the model at its true size. For example, CADstudio View11 [5] is a plug-in for the AutoCAD that can zoom DWG objects to be

displayed in real dimensions. However, the usage rate of 2D CAD is dropping since more and more designers, and engineers are using 3D CAD nowadays. This plug-in only works in the 2D CAD but not in the 3D CAD, so it is not suitable at present. This plug-in also requires the user to input the size of the monitor, which is not easy to know sometimes because the nominal size might not be the real size for some products.

In the field of virtual environments, there are some papers about the true-size perception. The research conducted by Emmanuelle Combe et al. studied the size perception in 1:1 display in different virtual environments such as the screen, AR, and VR(with and without head-tracking). The average perceived dimensions of participants in different media are all with errors less than 5%[3], which means displaying objects under the scale of 1:1 provides a high perception accuracy. Fei Shao et al. developed a virtual reality system to present the 1:1 car model on a large screen with dual stereo projectors[7]. This approach is practical but needs a wall screen bigger than a car, which requires huge space and makes it inconvenient. AR applications focusing on the same functions are also developed. CAD-to-AR[1] is one of the mature ones that enable the user to view the virtual model in an augmented reality environment. Although it is advantageous, it also has some drawbacks. The rendered model's size needs to be manually adjusted, which is tedious. It uses the computer's webcam, which means mobility is restricted, and users cannot move around the object to view it.

2   METHODOLOGY

As mentioned in the previous section, we developed A CAD plug-in and a Cloud-enabled AR APP for the true-size display. This section discusses technical details, including the program's principle and structure.

2.1   CAD Plugin for True-Size Display

3D CAD software shares a similar screen layout, and Autodesk Inventor is utilized in this project. Usually, the graphics window for displaying the model occupies most of the screen area.
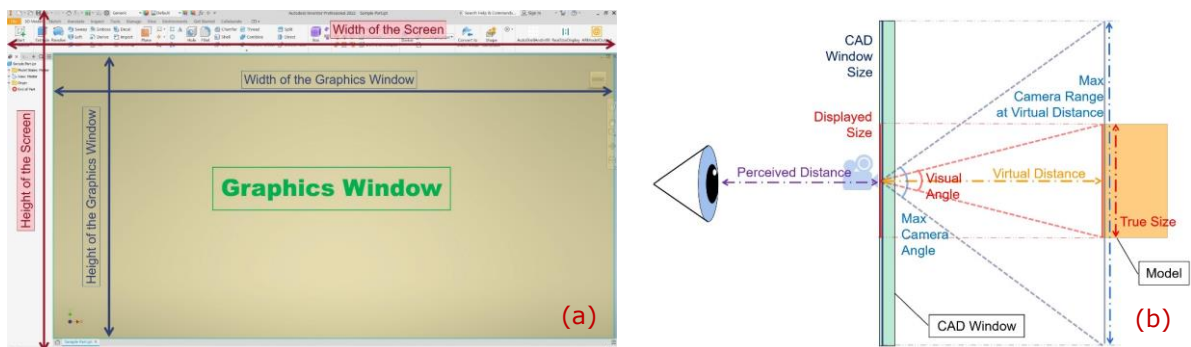

Figure 2: (a)The Screen Layout of Autodesk Inventor and (b) Size Perception when viewing a model displayed on the screen with Ture Size.

In Autodesk Inventor, the maximum camera angle is fixed, and the maximum camera range at a virtual distance can be modified directly by the API to set the camera's extent. The input parameters are the physical width and the height of the camera range. Aimed at displaying the true size of the model, the maximum camera range at a virtual distance should equal the size of the graphics window. The problem is now converted to determining the physical size of the graphics window.

It is unreasonable to let the user enter the physical window size since the measuring accuracy cannot be guaranteed, so an alternative method needs to be used. There is an Autodesk Inventor

API function that returns the pixel size of the graphics window, including width (Wp_{win}) and height (Hp_{win}), but its physical size is still unknown, and there is no API function in the software that can be used to retrieve them. Microsoft provides API functions in the Windows system that can be utilized to derive the physical size of the graphics window. The pixel size of the screen (Wp_{scr} and Hp_{scr}) can be obtained with GetSystemMetrics function while the physical size of the screen (W_{scr} and H_{scr}) can be obtained with GetDeviceCaps. Since the pixel size ratio should equal to the physical size ratio, the physical width, and height of the screen graphics window (W_{win} and Wp_{win}) can be calculated from Eqn. (1.1) and Eqn. (1.2)

$$W_{win} = \frac{Wp_{win}}{Wp_{scr}} \times W_{scr} \qquad (1.1)$$

$$H_{win} = \frac{Hp_{win}}{Hp_{scr}} \times H_{scr} \qquad (1.2)$$

Take the screen layout shown in Figure 2(a) as an example. When displaying on the 28-inch monitor with a 16:9 ratio under the resolution of 3840×2160, the pixel size of the graphics window is $Wp_{win} = 3364$ and $Hp_{win} = 1797$. The pixel size of the screen is $Wp_{scr} = 3840$ and $Hp_{scr} = 2160$ while the physical size of it is $W_{scr} = 62.8cm$ and $H_{scr} = 33.5cm$. Therefore, the physical size of the screen graphics window is $W_{win} = 55.01cm$ and $H_{win} = 27.87cm$. When displaying on the 15.3-inch monitor under the same aspect ratio and resolution, the pixel size parameters of the graphics window are the same, while the physical size parameters are different. There are $W_{scr} = 34.4cm$ and $H_{scr} = 19.4cm$. Thus, the physical size of the screen graphics window is $W_{win} = 30.14cm$ and $H_{win} = 16.99cm$.

Since the principle of realizing the True-size display is figured out, the next step is to write the plug-in script. Before writing codes, the process needs to be determined, while the flowchart has to be drawn. The flowchart of the plug-in script can be viewed in Figure 3.
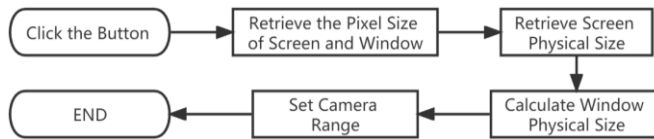

Figure 3: The flowchart of the plug-in script.

Autodesk Inventor provides an integrated developing environment using Visual Basic(VB) as the language to write script inside it. Therefore, the script can be quickly and conveniently tested and debugged. Also, detailed API documents are provided to support secondary development. A button that is used to activate the script can be created in the GUI of the Autodesk Inventor in the ribbon, turning the script into the form of a plug-in and improving the user experience. As for our plug-in, a button is created, which is shown in Figure 4.
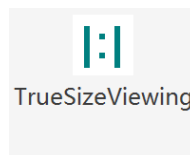

Figure 4: The icon of the TrueSizeViewing plug-in.

The key feature of the TrueSizeViewing plug-in is automatic zooming to achieve the 1:1 scale display with one click. The automatic zooming can be activated under any view. A typical process of using the plug-in on the 28-inch monitor under the front view is illustrated in Figure 5. Usually, the front view is the perspective that provides the most information. Therefore, it is chosen to be the sample

view. After switching to the front view and clicking the button of TrueSizeViewing, the zooming is carried out automatically, which is shown in Figure 5(d-f).
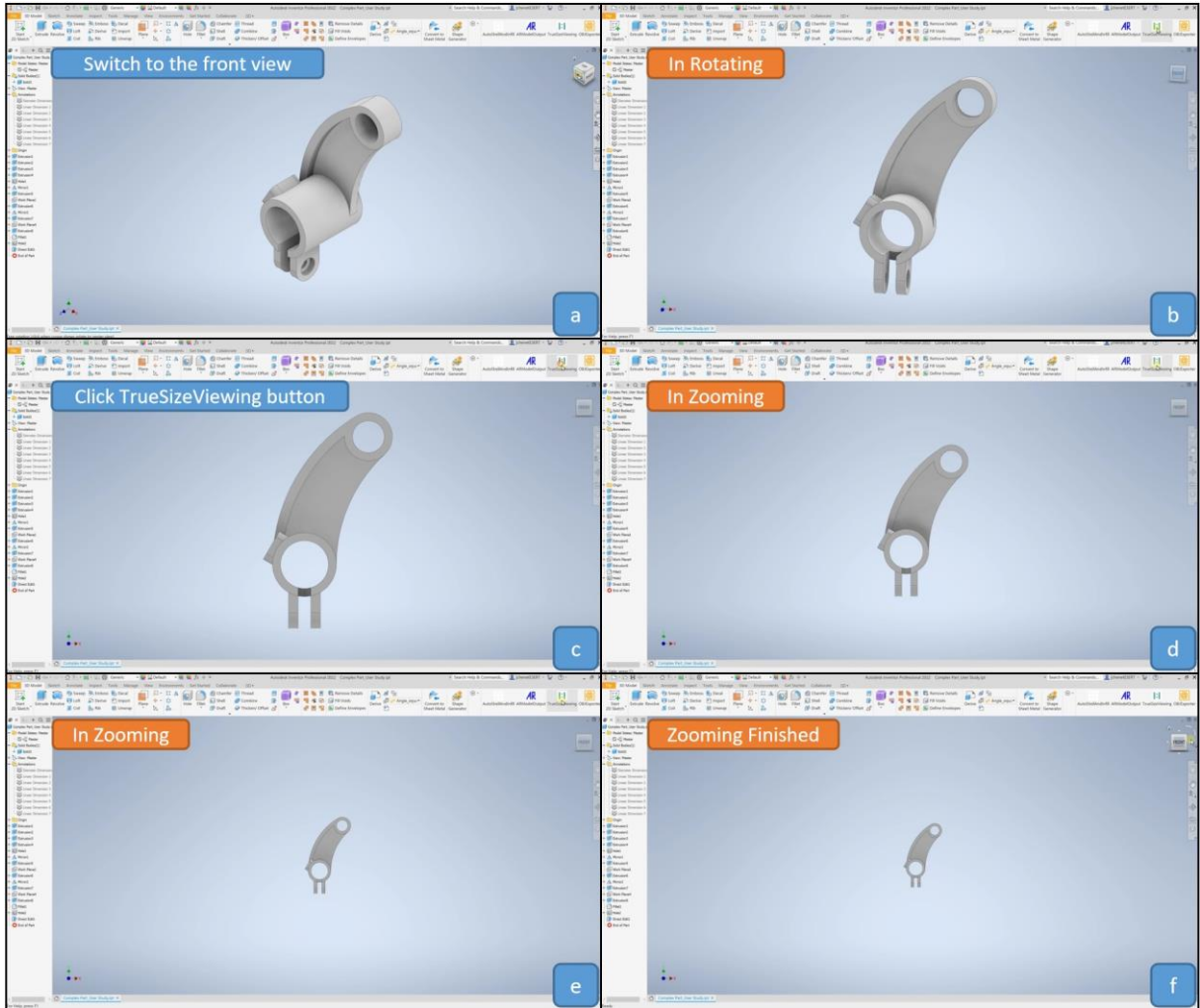

Figure 5: A typical process of using the TrueSizeViewing plug-in.

The effect of using the TrueSizeViewing plug-in is shown in Figure 6. A real part made by 3D printing is placed on screens as a reference. It can be seen from (a) and (b) that the same virtual model is with different sizes when displayed on different screens under the default scale. The virtual model on the 15.3-inch monitor is much smaller than the one on the 28-inch monitor. When the plug-in is activated, the real part and the virtual models on both screens are of identical size.

This indicates that the plug-in is adaptive and can zoom the virtual object to its true size and be utilized on the screen with different sizes without any manual input. The purpose of developing this plug-in is achieved successfully. Since many 3D CAD software use VB as the integrated developing language, the script can be easily migrated to other software by altering some API calling codes. Thus, the generality of this plug-in is significantly improved. This plug-in has been successfully migrated to another popular 3D CAD software: SolidWorks.
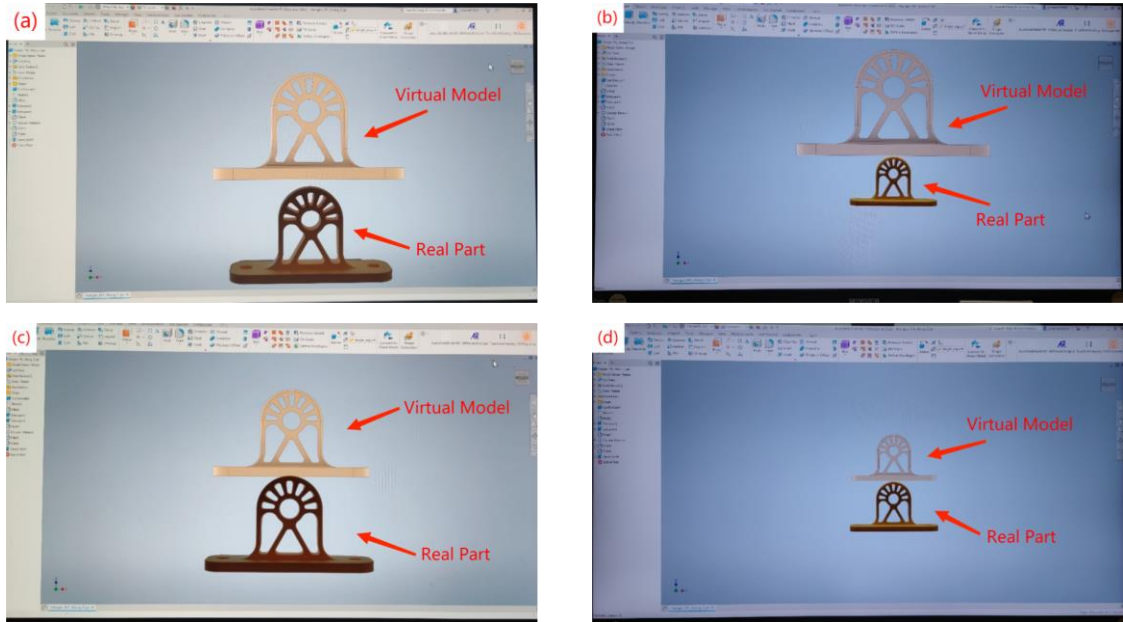
Figure 6: The same model displayed on the (a)15.3-inch monitor under default scale, (b) 28-inch monitor under default scale, (c) 15.3-inch monitor after activating the TrueSizeViewing plug-in, and (d) 28-inch monitor after activating TrueSizeViewing plug-in in Autodesk Inventor.

2.2 Cloud-enabled Mobile Augmented Reality App

Generally, there are two main types of AR depending on whether a marker is needed, namely marker-based and marker-less AR. Although the need for a pattern working as the marker to trigger the appearance of the model results in a lower degree of freedom, the marker-based AR can render the virtual part with higher dimensional accuracy by dynamically referring to the marker size without powerful calculation resources [9]. This advantage makes it more suitable for the application of True-Size Display. The virtual model is of good dimensional accuracy for the marker-less AR when it is just placed. However, when moving the camera, its size will be of significant error since the deviation accumulates when using the gyroscope to estimate the displacement. This problem is illustrated in Figure 7.
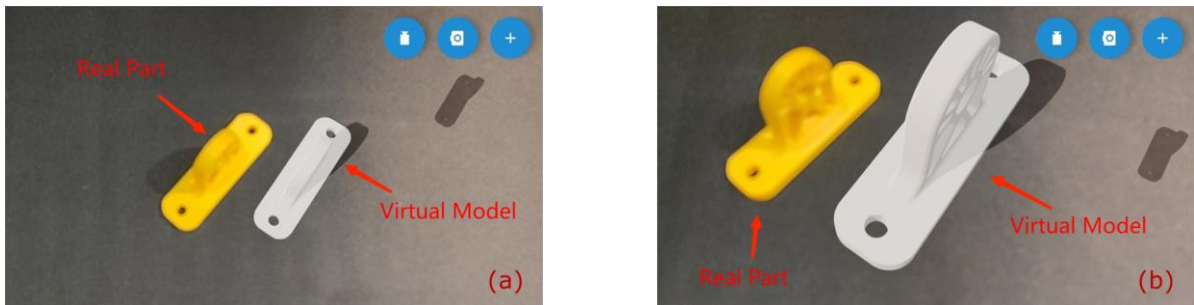

Figure 7: Pictures about using the AR Viewer(a marker-less AR APP), which are (a) the moment that the virtual is placed and (b) after moving the camera closer.

Instead of deploying the App on the PC, the marker-based App is deployed on mobile devices because it has higher mobility. The viewing experience is more like the natural behavior of observing a real object. The purpose of uploading the model to the cloud server and then downloading it to a mobile device such as a smartphone instead of direct file transmitting is to reduce the operational steps.

Unity is selected as the platform for development because plenty of libraries and toolkits, such as the XR Interaction Toolkit, enable the developer to focus on achieving the goal instead of being obsessed with programming. The APP is run on Android because the Android APP's development process is less restricted than IOS. Google provides ARCore, a software development kit, for specific devices which satisfy the requirements. Under the application of marker-based AR, ARCore uses the camera to track the marker and render the object with the corresponding size and direction. The rendered object will also be changed based on the gyroscope and accelerometer when no marker is captured in the view of the cameras.

The structure of the whole process is shown in Figure 8. When the activation button is clicked in the Autodesk Inventor, A VBA Macro will be run and open the Format Converter to convert the 3D model from the original format '.ipt' to the common format '.obj'. The generation of the '.obj' file will open the AssetBundle Creator in Unity and convert the '.obj' 3D Model into AssetBundle format that the APP can dynamically load. The completion of this conversion will trigger the running of the Uploading Script that uploads the local file (Unity AssetBundles) to the cloud. If the user clicks the button in Android AR App on the smartphone, the 3D Model will be downloaded from the cloud and ready for rendering. Targeting the camera at the Marker will activate the Image Tracking Function, triggering the Model Rending Function and making the 3D Model visible on the smartphone.
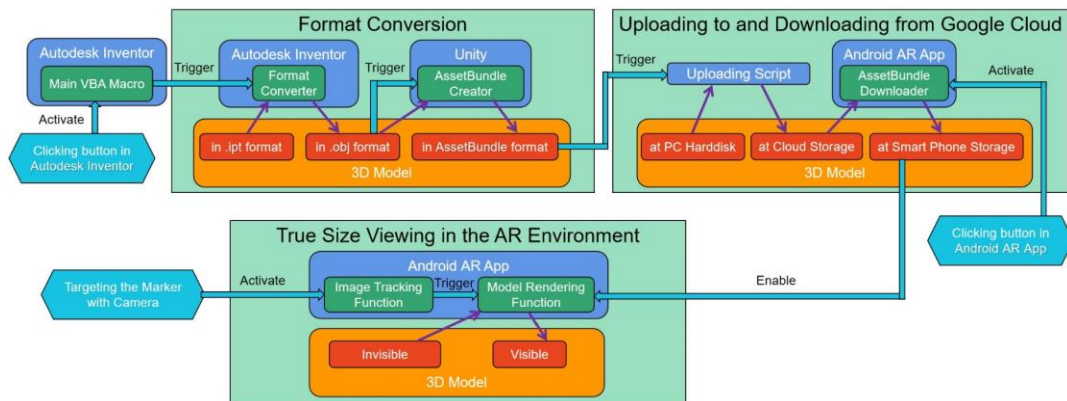

Figure 8: Working Processes for the AR True-Size Viewing.

The main contribution of this APP is that it is the first attempt to establish a direct connection between AR APP and the CAD software. Instead of converting the 3D model into a common format, then sending it to the smartphone with a cable or Bluetooth connection and browsing a brunch of folders for the correct file on the smartphone, a simple click on a button in the CAD will make the model synchronized on their smartphone. The format transformation and transmission process are integrated and run automatically, so users can skip tedious operation steps when they want to view the CAD displayed model in the AR environment. Compared to the traditional method of viewing the 3D model with AR, which interrupts the design, the proposed APP can significantly reduce the impact on the smoothness of the design process.

The actual use effect of the APP is shown in the figure below (Figure 9). The picture shows that the rendered 3D model has the same size as the 3D printed object from the oblique view, the front view, and the top view. The texture and shadow of the virtual model and the real part are also similar. With this APP, the necessity of 3D printing the model, which consumes a lot of time, decreases significantly in the design phase. Viewing the model in the augmented reality environment also brings a better immersion experience than planar viewing.
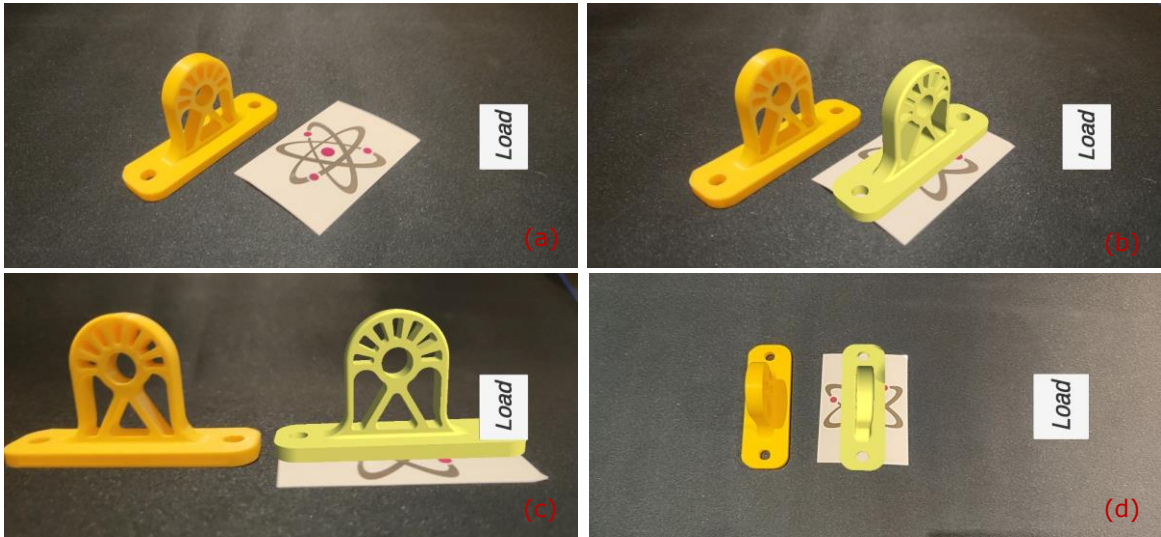
Figure 9: Pictures about using the Android AR App to view the 'Hanger'. When (a) the 'Load' button is not clicked, the 'Load' button is clicked when viewing from the (b) Top-Left Corner, (c) Front, and (d) Top.

3   USER STUDY ON TRUE-SIZE DISPLAY

The user study is conducted to verify the plug-in can reduce the time and increase accuracy in the size perception. The process of precepting dimensions of the object is simulated by selecting the correct real object from a group of objects that share the same features but differ in size corresponding to the virtual model. During the experiment, participants are welcome to give their opinions and suggestions on the plug-in.

3.1 Apparatus

Three groups of parts were prepared: the simple part group, the complex part group, and the curved-surface part group. The simple part is a cylinder with a square hole in the middle(diameter = 10mm and height = 5mm), while the complex part is a curved sturt with several fixing features(Height = 25 mm and the center distance = 44.72 mm). The duck-like artistic model is the curved-surface part(width = 20mm). The standard (1.0x) virtual 3D models of three groups are shown in Figure 10.
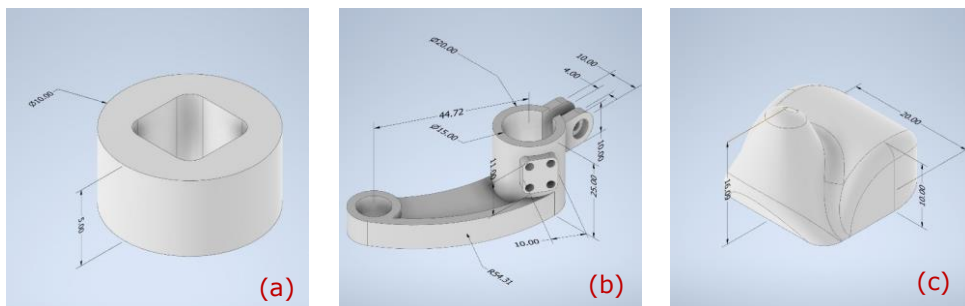

Figure 10: 3D models of the (a) simple part group, (b) complex part group, and (c) the curved-surface part group.

Each group consisted of 7 units with identical features but different sizes (varied by zooming). All parts were fabricated by 3D printing under the same setting parameters, so they are with the same appearance and tactile feeling. Engineering drawings were printed on A4 paper (from Double A), and 3D models were displayed in the Autodesk Inventor 2022 on a laptop with a 15.3-inch 4k screen (Gigabyte Aero 15 XA-2019). A timer software was used to record the time.

Figure 11: Pictures of 3 groups of parts, which are: (a) the simple part group, (b) the complex part group, and (c) the curved-surface part group

3.2 Procedure

All participants attended a training session and 3 experimental sessions. The training session was designed to increase participants' familiarity with the 3D CAD software to avoid potential latency. 3 experimental sessions were with the same task of selecting the correct physical parts. The difference was the referencing medium. The drawings and the models are all with annotations. For different sessions, the medium was:

Session 1: Paper drawing (with a scale of 1:1)
Session 2: 3D CAD with rulers
Session 3: 3D CAD with TrueSizeViewing plug-in

In Session 1, a paper drawing was provided, and participants could place physical parts on the paper to select the right one. In Session 2, the virtual model was displayed on the screen with annotations but not its true size, so the participant could only read dimensions and use rulers to measure the physical parts. In Session 3, the virtual model is displayed with annotations in its true size on the screen. Participants could place the part on the screen for selection. Each session was composed of 3 tests using 3 groups of parts. The medium was provided when the participant claimed to be ready and started the timer. Once the participant found the correct part, the timer was stopped, and the time was recorded. Pictures of using different mediums are shown below in Figure 12.
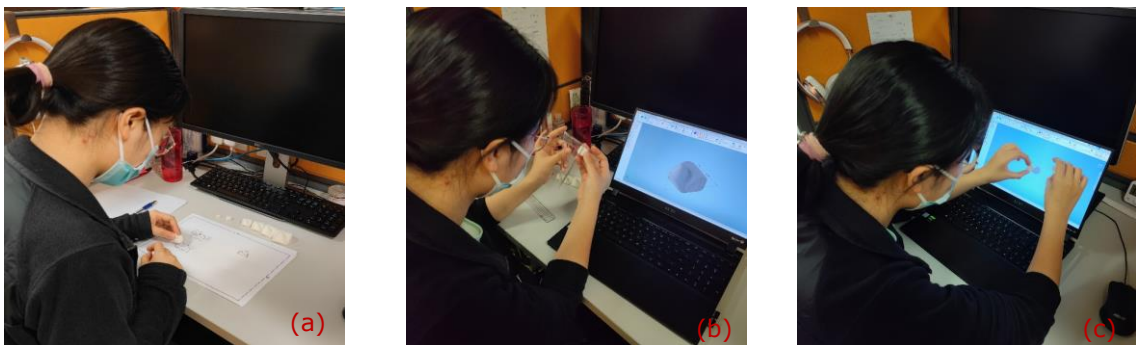

Figure 12: Pictures of a participant experimenting with different mediums (a) Paper drawing, (b) 3D CAD with rulers, and (c) 3D CAD with TrueSizeViewing plug-in.

3.3 Participants

Totally, there were 10 participants aged between 23 and 34 (M =25.8, SD = 3.9). Among all participants, 7 of them were female, while 3 of them were male. 7 participants had background knowledge of engineering drawing, and the rest were not.

3.4 Results

The result of the experiment is shown in Figure 13. Among all groups, the average time for paper drawing is much shorter than for 3D CAD with rulers, while the average time of using 3D CAD with TrueSizeViewing ranks in the middle. The time reduced in the tests for the simple part is not as ample as the one for the complex part as well as the curved-surfaced part. The average time of the test on selecting the complex part is the greatest in Session 1 and Session 2 but lower than the one of the curved-surfaced part in Session 3. The deviation in Session 2 with the medium of 3D CAD with rulers is more significant than in the rest two, especially for the complex part.
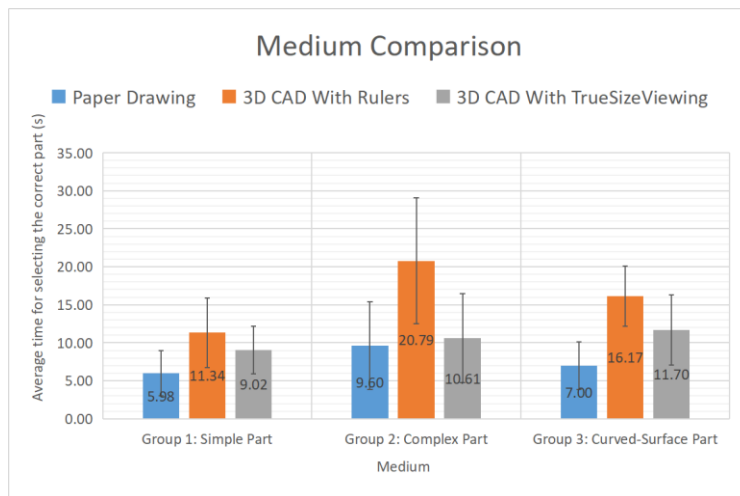

Figure 13: Result of the medium comparison.

3.5 Discussion

This experiment indicates that TrueSizeViewing can shorten the time consumption of choosing the correct part. The reason why it is still not comparable to the paper drawing might be the lack of familiarity with using the plug-in. If the participants use the plug-in more frequently, the average time can be further lower.

During the experiment, participants shared some interesting opinions. Participant II said that she is more familiar with 2D drawing and very sensitive to the dimensions, and she was not used to 3D CAD. Because of that, the plug-in cannot decrease the time of selecting the correct physical part. Evenly, her time in Session 2 for choosing the complex part and the curved surfaced part was shorter than in Session 3, which means the plug-in became a barrier for her. Participant V said he is highly familiar with the Autodesk Inventor, and he felt that the plug-in was convenient. His time spent in Session 3 is significantly lower than in Session 2. Participant VII said that he had no idea about the engineering drawing. He could hardly understand the 2D drawing but representing a part in 3D is more intuitive and understandable. Also, the plug-in can help him understand the part size without reading and memorizing many annotations, which saves him a lot of time. According to Participant IV, figuring out the part size with an oblique view is much easier than with an orthogonal view. The traditional 2D drawing presents parts mainly in orthogonal views, making it hard to understand the part when looking at one view.

4   USER STUDY ON CLOUD-ENABLED AR APP

With the purpose of verifying and evaluating the developed AR APP, several user studies are conducted.

4.1 Preparation Time Comparison between the Manual Upload and Cloud Synchronization

4.1.1   Purpose of the experiment

The main purpose of this experiment is to find out the difference in time consumption between the manual upload for traditional AR App and cloud synchronization for our App and quantify the improvement of our approach

4.1.2   Apparatus and Procedure

The 3D model used for the experiment is the one shown in Figure 10(b) but without random scaling. Tests are carried out on a laptop with a 15.3-inch 4k screen (Gigabyte Aero 15 XA-2019) and a smartphone(Xiaomi 11 Ultra).

All participants are required to view the model with the traditional AR App(AR Viewer) and the cloud-enabled AR App(developed by us) 8 times for each. In using the traditional AR App, the user will need to manually do the format conversion, file transimission, and model scale adjustment. The first 3 times will be used as the training test, and it will not be recorded. The last 5 times will be recorded and used for analysis. They will all be asked the question of which method they prefer.

4.1.3   Participants

There were 5 participants in total, aged between 21 and 28 (M =24.2, SD = 2.6). Among all participants, 2 of them were female, while 3 of them were male.

4.1.4   Result

The result of the experiment is shown in Figure 14. The result illustrates that the time consumption of the preparation of the cloud-enable App is much shorter than the traditional one. The average time reduction of all participants is 66.7%. All participants prefer using the cloud-enabled APP.
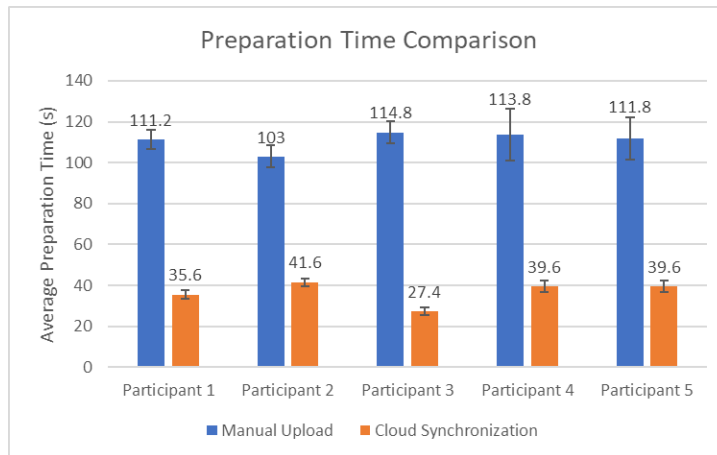

Figure 14: Result of the preparation time comparison.

4.1.5   Discussion

The cloud-enabled App significantly shortens the meaningless time consumed in the manual operation and greatly improves the working efficiency as well as the user experience.

4.2 Design of the Multi-use Cellphone Holder

An industrial designer usually focuses more on the aesthetic aspect and pays less attention to the dimension, so it is necessary for them to perceive the real size to design a feasible product(seen in Figure 15(a)). Communication is of great importance in the design phase, while the traditional method for this is to look at the same monitor, and one will ask another one to do the operation like moving, rotating, and zooming, which is ineffective. With AR App, the viewing will be more effective and more comfortable(seen in Figure 15(b)).

4.3 CT Scanned 3D Model Viewing and Surgery Planning

3D model generated by CT Scanning is now wildly used. Due to the limited size of the monitor, 3D models are usually viewed under a reducing scale. The surgeon can hardly have an intuitive understanding of the size of the tumor or other lesions. When planning for the surgery, the size is of great importance, and it might influence the selection of the surgical approach. The AR App can also be applied to solve this problem. The picture of this application can be viewed in Figure 15(c).
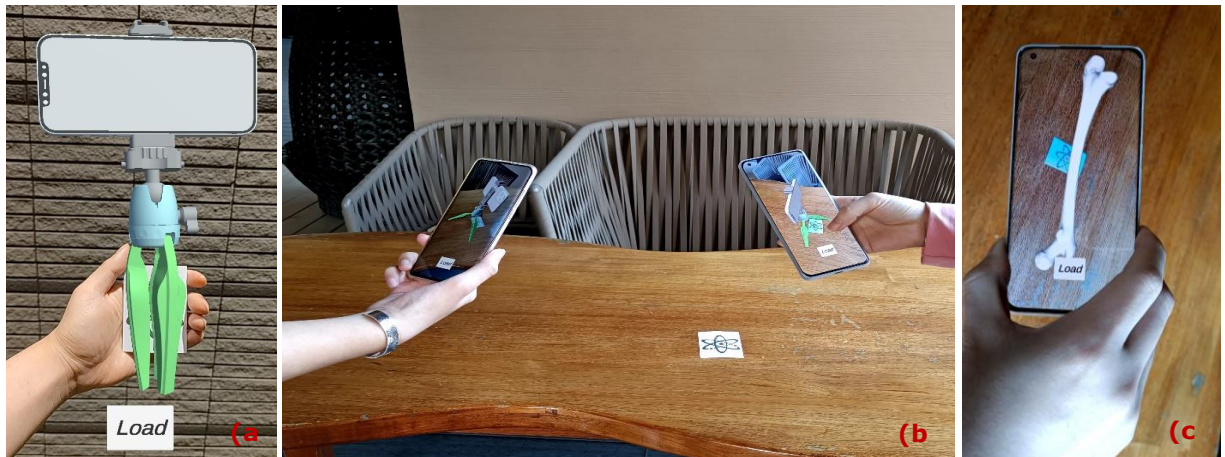

Figure 15: Pictures about (a) using the Android AR App to view the cellphone holder in hand, (b) two viewers using the AR App simultaneously, and (c) viewing a femur bone generated by CT Scanning

5   CONCLUSION

Incorrect size perception when using CAD brings trouble in both designing and viewing. Measuring the dimensions and imaging the part with a ruler as the size reference usually does not work for the complex part. Manually scaling the model on the screen is time-consuming and troublesome. The proposed TrueSizeViewing CAD plug-in automated the scaling process and made displaying the part with its true size on the monitor easier and faster, and the experiment verified it. The Cloud-enabled AR APP increases the similarity between viewing the virtual model and the real part. A user study on the product design was conducted, and it was found that the APP improved the design speed and communication efficiency. Another user study on lesion real-size visualization illustrated the potential of the AR APP to be utilized in other fields as assistive technology. The True View Platform, composed

of the CAD plug-in and the Cloud-enabled AR App, Enhanced the size perception and enabled the user to work more effectively. The true-size viewing plug-in has filled the missing true-size display function in mainstream 3D CAD software. Also, the problem caused by the time-consuming and tedious operations of transferring the format and transmitting the file is solved by the cloud-enabled AR APP.

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