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

Authors:
Junjian Chen, junjian.chen@connect.ust.hk, The Hong Kong University of Science and Technology (GZ)
Zhongyuan Liao, zy.liao@connect.ust.hk, The Hong Kong University of Science and Technology (GZ)
Yi Cai, yicai@ust.hk, The Hong Kong University of Science and Technology (GZ)

Introduction:
Compared with 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]. 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[5][10]. A familiar object's perceived size remains identical regardless of the changing distance[8]. This phenomenon is known as size constancy[11], and it helps humans estimate the size of unfamiliar objects. However, the part in the CAD is usually of low familiarity and presented without any familiar object, so the size perception is based on the perceived target distance and the visual angle. When observing a virtual object shown on the monitor, the convergence of two eyeballs focusing on the same object plays the most important role among all cues[3][9]. 3D CAD software uses the 2D image of a virtual camera targeting the model located at a virtual distance to display 3D models. 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[12]. 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. Fig. 1 is listed below to illustrate the display method in the 3D CAD more clearly.
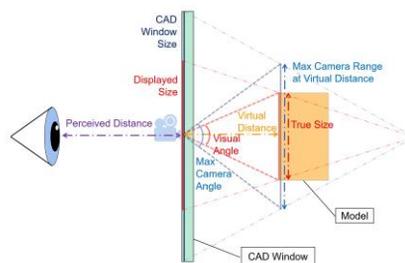

Fig. 1: Size Perception when viewing a model displayed on the screen.

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 of inaccurate size estimation. 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, although a plug-in for 2D CAD exists[4]. Therefore, manually zooming is needed to display true-size 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. 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)[6]. Their APP, which is called CAD-to-AR, can render the model in a real environment, but it is based on the webcam on the computer[1], which means it is not convenient to use it. Therefore, a Cloud-enabled mobile Augmented Reality App is also developed.

Methodology:

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.
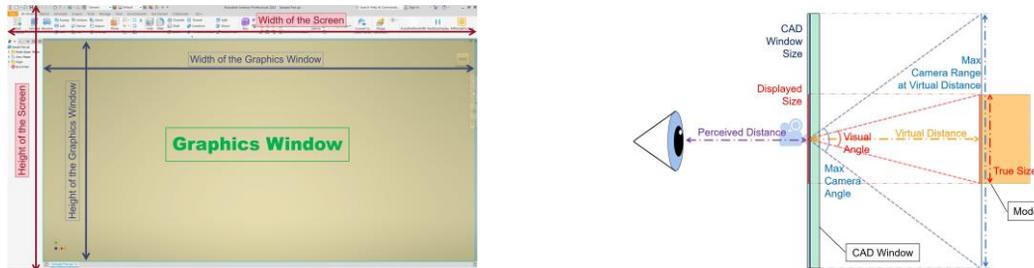

Fig. 2: (a)The Screen Layout of Autodesk Inventor and (b) Size Perception when viewing a model displayed on the screen with Ture Size

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)

$$W_{win} = \frac{Wp_{win}}{Wp_{scr}} \times W_{scr} \tag{1.1}$$

$$H_{win} = \frac{Hp_{win}}{Hp_{scr}} \times H_{scr} \tag{1.2}$$

Take the screen layout shown in Fig. 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 $3840 × 2160$, 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 $H_{win} = 16.99cm$. The effect of using the TrueSizeViewing plug-in is shown in
Fig. 3, and the model displayed on different screens and the real part made by 3D printing are of identical size.
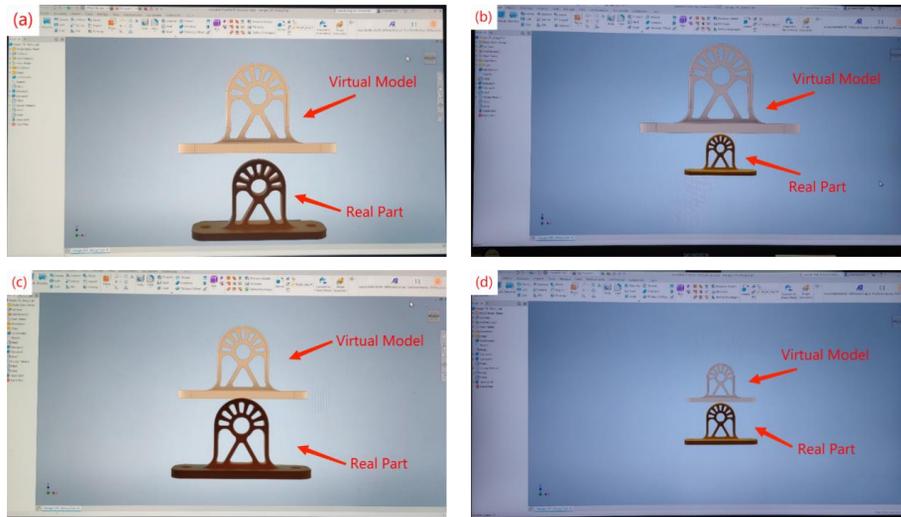

Fig. 3: The same model displayed on the (a)15.3-inch monitor under default scale, (b) 28-inch monitor under default scale, (c) 15.3-inch monitor after activating the TrueSizeViewing plug-in, and (d) 28-inch monitor after activating TrueSizeViewing plug-in in Autodesk Inventor.

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[7]. 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
Fig. 4.

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.
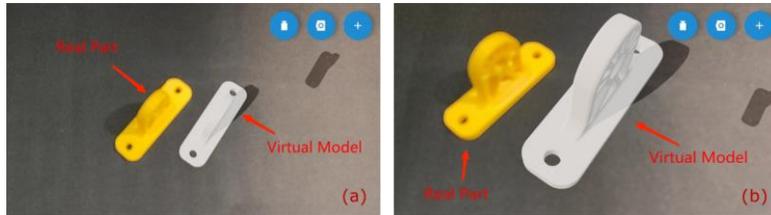
Fig. 4: Pictures about using the AR Viewer(a marker-less AR APP), which are (a) the moment that the virtual is placed and (b) after moving the camera closer.

The structure of the whole process is shown in
Fig. 5. 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.
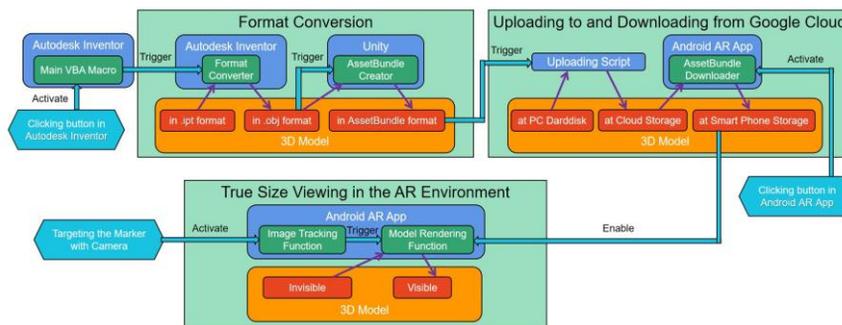

Fig. 5: Working Processes for the AR True-Size Viewing.

The actual use effect of the APP is shown in the figure below (
Fig. 6). 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. With this APP, the necessity of 3D printing the model decreases significantly in the design phase.

Case Study:
1) 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 they must perceive the real size to design a feasible product. Communication is of great importance in the design phase, while the traditional method is to look at the same monitor. One will ask another to do operations like moving, rotating, and zooming, which is ineffective. With AR App, the viewing will be more effective and more comfortable.
2) 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.
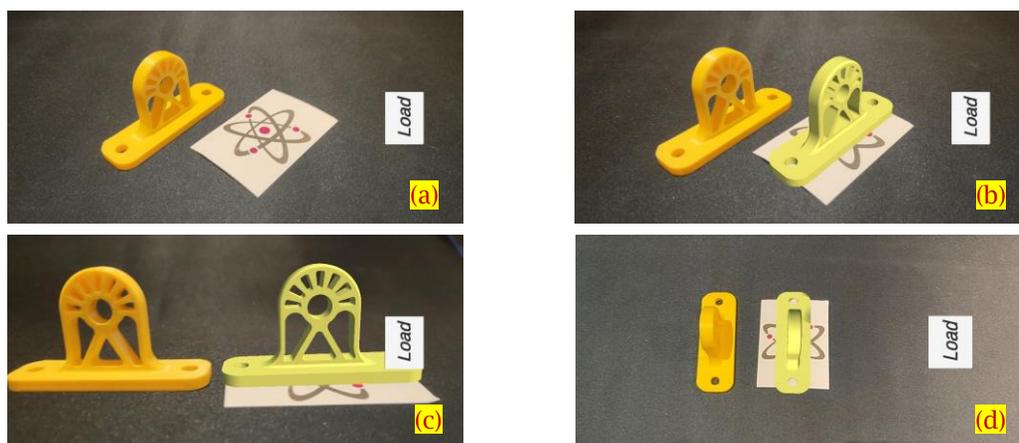

Fig. 6: Pictures about using the Android AR App to view the 'Hanger'. When (a) the 'Load' button is not clicked, the 'Load' button is clicked when viewing from the (b) Top-Left Corner, (c) Front, and (d) Top.
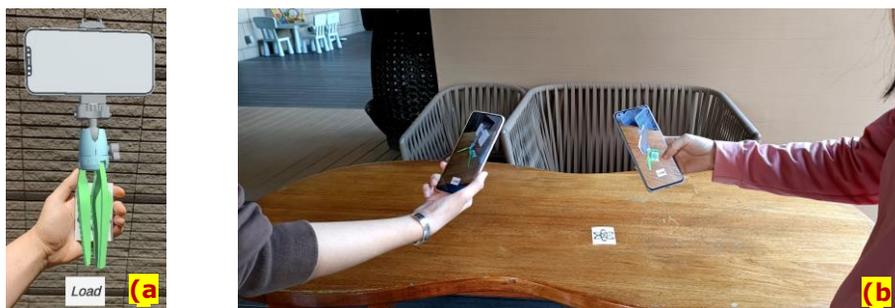

Fig. 7: Pictures about (a) using the Android AR App to view the cellphone holder in hand and (b) two viewers using the AR App simultaneously.

Fig. 8: Viewing a femur bone generated by CT Scanning.

Conclusions:
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. TrueSizeViewing CAD plug-in automated the scaling process and made displaying the part with its true size on the monitor easier and faster. Cloud-enabled AR App increased the similarity between viewing the virtual model and the real part. Its capability of improving the design speed and communication efficiency has been well demonstrated in case study 1, while case study 2 illustrates the potential 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.

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