

# Research on Key Technologies of Substation Simulation System based on VR/AR

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## Abstract

**By combining augmented reality technology and AR Vuforia components, this project created a device display and disassembly simulation system specifically designed to simulate critical equipment such as circuit breakers and isolation switches. The system uses AHE-CLAHE image enhancement algorithm to improve the image quality, improve the user experience, make the equipment display and operation process more intuitive and interactive, and deepen the students' understanding of the equipment and operation skills. This project effectively supports the development of teaching resources and improves the teaching effect.**

## Keywords

**Augmented Reality; AHE-CLAHE; Substation; AR Vuforia.**

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## 1. Introduction

With the increasing number of college students, the traditional substation practice method gradually shows its limitations. These methods rely too much on book theory, which is disconnected from the real working environment, and the scarcity of internship opportunities cannot meet the growing needs of students. Safety is also a challenge. Therefore, it is urgent to develop a new model of internship education. The introduction of modern technology such as virtual reality and the construction of virtual internship platform are not only safe and practical, but also help to train students' practical skills and innovative thinking more effectively.

At the same time, a number of studies in recent years have also demonstrated the potential and effectiveness of augmented reality (AR) technology in multiple fields. For example, research from the California Institute of Technology shows that using AR commands can speed up task completion and reduce psychological and time pressure<sup>[1]</sup>. The handheld AR application developed at the University of Waterloo significantly improves the efficiency of tube shaft assembly and is especially helpful for people with poor spatial cognition. Research at the University of Pisa has launched a projected AR head-mounted display that provides accurate real-time guidance during surgery with an error of just 0.3 mm<sup>[2]</sup>. The AR Electronic Lab application developed by Yildiz Technical University reduces the dependence of e-education on traditional physical devices<sup>[3]</sup>. The research from the Federal University of Para demonstrates a low-cost AR application for data visualization, driving the development and standardization of AR technology<sup>[4]</sup>. These studies demonstrate the tremendous potential of AR technology to increase productivity, drive innovation in education, and improve the accuracy of medical practices<sup>[5]</sup>. Therefore, by integrating augmented reality technology with AR

Vuforia components, the project successfully created an innovative device display and disassembly simulation system.

## 2. Case Development and Implementation

### 2.1 Case Development Process

In the process of making augmented reality software, development based on the Unity platform can be divided into three stages: early, middle and late. The early stage is mainly project preparation, including clear software objectives, requirements, development plans and resource preparation, while setting up the development environment of Unity and necessary plug-ins. The middle stage is the main editing work, including creating the Unity project, importing the materials (such as models, textures, sound effects, etc.), editing the scene, and designing the user interface. In the later stage, the software is tested and repaired, and finally packaged and released, so that the software can be downloaded and used by users. This process, from project preparation to final release, ensures that the software meets the intended goals and user needs. Figure 1 shows the specific development process.

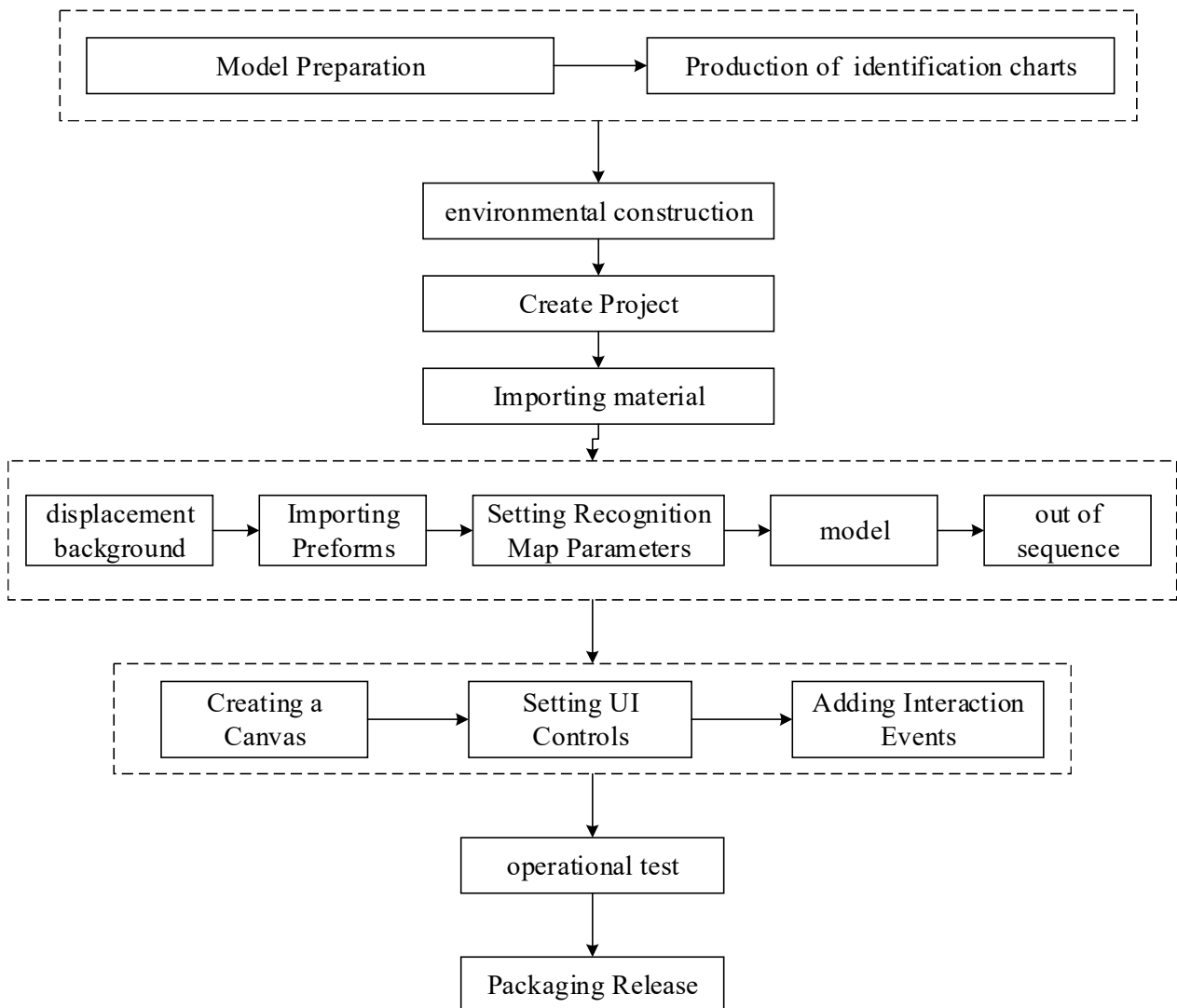


Figure 1. Case Development Flowchart

### 3. Display Platform and Space Construction

#### 3.1 Database Creation based on Vuforia

The main task in creating a VR database is to integrate all design elements into Unity3D to create a complete interactive application. Using the Vuforia SDK, it is possible to convert real-world objects into an enhanced virtual experience. The process includes obtaining a Vuforia license code in Unity3D, creating and managing a database (for storing augmented reality recognized images), and uploading the recognized images to the Vuforia website. The uploaded images need to be adjusted for optimal recognition, including clear boundaries and high contrast. The official website will rate the images, and images with less than a 3-star rating will be difficult to recognize. Once this is done, download the Unity resource pack from the official website and import it into the project. These steps ensure smooth development of augmented reality applications on mobile devices and optimization of recognition performance. Among them, Figure 2 shows the Target Manager database creation and Figure 3 shows the Target Manager database after image upload.

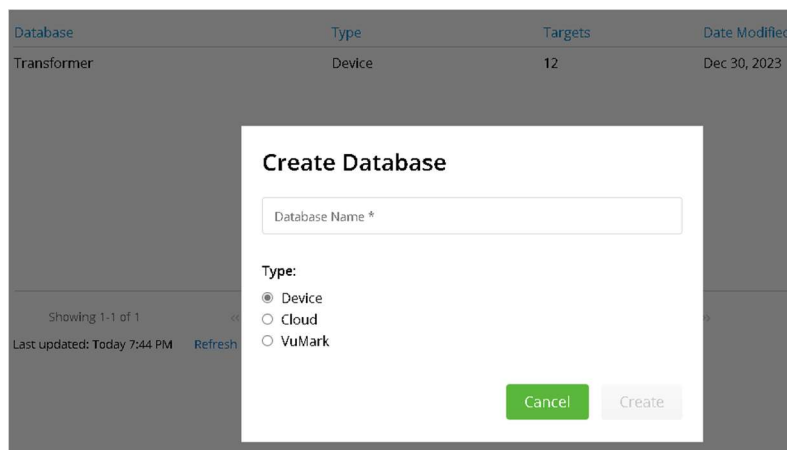


Figure 2. Target Manager Database Creation

Target Name	Type	Rating	Status	Date Modified
fangdianbang	Image	★★★★★	Active	Dec 30, 2023 10:55
bileiqi	Image	★★★★★	Active	Dec 30, 2023 10:21
dianliuhuganqi	Image	★★★★★	Active	Dec 30, 2023 10:08
dianyahuganqi	Image	★★★★★	Active	Dec 30, 2023 10:04
duanluqi	Image	★★★★★	Active	Dec 29, 2023 21:55
gelikaiguan	Image	★★★★★	Active	Dec 29, 2023 21:51
jiezhisunhaoceshiyi	Image	★★★★★	Active	Dec 29, 2023 21:48
zhiliugaoyafashengqi	Image	★★★★★	Active	Dec 29, 2023 21:31
xianliudianzu	Image	★★★★★	Active	Dec 29, 2023 21:10
shuxianweianbiao	Image	★★★★★	Active	Dec 29, 2023 20:56
zhiliugaoyafashengqi002	Image	★★★★★	Active	Dec 29, 2023 20:50
bianyayqi	Image	★★★★★	Active	Dec 29, 2023 09:52

Figure 3. Target Manager database after image uploading

#### 3.2 Unity-based Platform Interactive Functionality Implementation

First, perform the Unity engine installation, followed by downloading and installing VS2019 as the compiler, along with the SDK, JDK and NDK to set up the Android development environment. Find and install the Vuforia plugin via PackageManager. In the Hierarchy view, configure the ARCamera for recognizing images, adjust the corresponding parameters in the Inspector view, select the imported database and specify the images to be recognized. Next, import the 3D model into Unity and place it

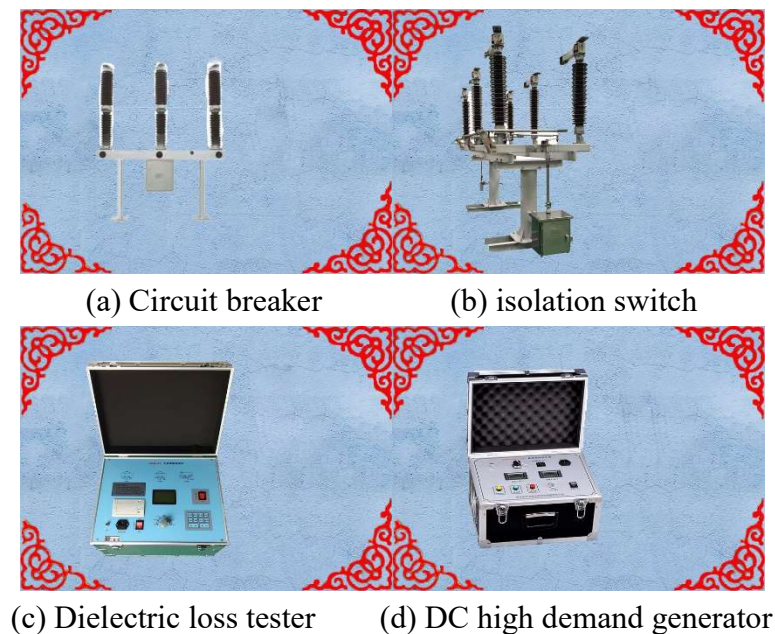
in the same directory as the Main Camera. Adjust parameters such as the model's position, rotation angle, and scaling. Add colliders and scripts to the model to enable interactive features such as scaling and rotation. Finally, the application is packaged and sent to an Android device, such as a smartphone or tablet, where it can be installed and used on these mobile devices.

### 3.3 Functional Realization

To meet the needs of teachers and students, the augmented reality software needs to have image recognition and model display capabilities. Before starting the operation, make sure that the required materials have been imported into the Assets resource directory of the project. Next, create a new folder named ARTransformer within the project directory and place the prepared recognition image into this folder.

#### (1) Image recognition function

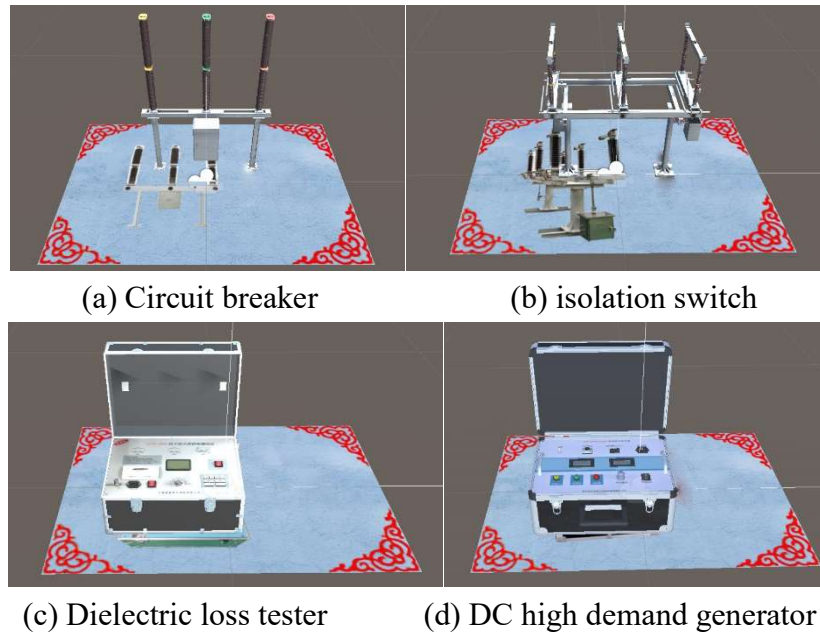
In order to realize the image recognition function, it is necessary to complete the operation of "placing the recognition map → setting Image Target parameters". Place the prepared recognition image in the EasyAR development environment, which can be placed in the appropriate position in the scene by drag-and-drop. Then, set the parameters of the image target, including name, size, scale, rotation angle, etc. These parameters will be used for subsequent image recognition. These parameters will be used in the subsequent image recognition process. After completing the above operations, then the camera can recognize the placed recognition map, and part of the recognition map is shown in Figure 4.



**Figure 4.** Partial identification map

#### (2) Model Display Function

Drag and drop the model as a sub-object under Image Target in the Hierarchy Panel, and then make it display in the center of the screen by adjusting the parameters such as position, size and rotation angle. In this way, when the camera focuses on the recognition map, the corresponding 3D model will appear on the image, and when the recognition target disappears, the model will disappear with it. The effect of the model in unity is shown in Figure 5.



**Figure 5.** Model effect in unity

### (3) Interactive Interaction Functions

The interactive function applied in the system is gesture interaction, by sliding the screen, the user can freely rotate the model in order to observe all angles. And by using two fingers to perform pinch or open gestures, zoom-in and zoom-out operations of the model can be realized. This interaction provides a more intuitive and flexible control experience, enabling users to easily operate the rotation, zoom-in and zoom-out of the model.

### (4) Device introduction function

To realize the device introduction function, i.e. to trigger a pop-up text introduction of the device by clicking a button, create a Canvas under the Image target; then, add a button in the Canvas and bind the click event. Next, write a function to control the display and hiding of the introduction text in the button click event, and assign the corresponding text content to the UI Text component. In this way, when the user clicks the button, the introduction text of the device will be shown or hidden in the scene.

## 4. Enhancements to Vuforia Image Recognition Vuforia

In AR, optimizing the image recognition model is the key to improve accuracy and performance. Methods include image preprocessing, feature extraction and selection, model training and optimization, image database management, algorithm optimization and hardware acceleration, and real-time performance optimization. The accuracy and real-time performance of image recognition can be improved by preprocessing images, extracting useful features, training and optimizing models, managing image databases appropriately, optimizing algorithms, and utilizing hardware acceleration. This improves the user experience of AR applications and ensures that images are accurately recognized and tracked, providing users with a better AR interaction experience.

### 4.1 Basics of Histogram Enhancement Techniques

Histogram is a tool used for statistical probability distribution of gray level of an image. Histogram enhancement technique improves the image quality by modifying the histogram of the image. The strategy of modifying the histogram determines the enhancement effect. By choosing the appropriate strategy, the image contrast, sharpness and color can be enhanced.

In the image enhancement process, let  $x$  and  $y$  refer to the gray values of the pixels before and after enhancement, respectively. Their corresponding probability density functions of gray scale

distribution are  $P_x(x)$  and  $P_y(y)$ . To simplify the analysis, the pixel gray values are set to be normalized in the interval  $[0,1]$ , where  $x=0$  corresponds to black, while  $y=1$  corresponds to white. The  $x$ -values within the  $[0,1]$  interval are processed by applying the transform function:

$$y = T(x) \tag{1}$$

For the transform function  $T(x)$ , it must follow two principles: (1) it exists as a monotonically increasing function, and (2) its function values range between  $[0,1]$ . The first principle ensures that the gray levels follow a natural order from black to white, while the second principle ensures that the transformed pixel gray values remain within acceptable bounds. The inverse transformation from  $y$  to  $x$  is:

$$x = T^{-1}(y), 0 \leq y \leq 1 \tag{2}$$

According to probability theory, if  $P_x(x)$  and the transformation function  $y = T(x)$  are known, and it is specified that the variable  $y$  also satisfies the conditions (1) and (2), then one can introduce  $T^{-1}(y)$  single-valued monotonically increasing function. Then there are:

$$P_y(y) = \left[ P_x(x) \frac{dx}{dy} \right]_x = T^{-1}(y) \tag{3}$$

Histogram enhancement technique improves the visualization of an image by adjusting the gray level probability density function of the image through the transform function  $T(x)$ .

#### 4.2 Histogram Equalization

For a continuous image, the transformation function is:

$$y = T(x) = \int_0^x P_x(x) dx, 0 \leq x \leq 1 \tag{4}$$

The right hand side of this equation is the Cumulative Distribution Function (CDF), from which the derivation of  $x$  has:

$$\frac{dy}{dx} = P_x(x) \tag{5}$$

Substituting into (3) yields:

$$P(y) = \left[ P_x(x) \frac{1}{P_x(x)} \right]_x = T^{-1}(x) = 1, 0 \leq x \leq 1 \tag{6}$$

After the transformation is performed, the variable  $y$  remains in the domain of definition and satisfies a uniform probability density distribution, i.e.,  $P_y(y)$  is uniformly distributed. From the point of view of image enhancement, this is equivalent to extending the dynamic range of the pixels. Such a

transformation significantly changes the brightness and contrast of the image. A significant change in the contrast of the image will be able to be clearly observed when MATLAB simulations are performed.

For discrete image, the probability value of gray level  $x_k$  is:

$$P_x(x_k) = \frac{n_k}{n}, 0 \leq x_k \leq L-1, k = 0, 1, 2, \dots, L-1 \quad (7)$$

where  $n$  denotes the total number of pixels in the image,  $n_k$  denotes the number of pixels in the image in which the  $k$ th gray level occurs,  $L$  denotes the total number of gray levels, and  $P_x(x_k)$  denotes the probability of the  $k$ th gray level. This corresponds to Eq. (4) for continuous images in discrete form: Here,  $n$  represents the total number of pixels within the image,  $n_k$  is the number of pixels of a particular gray level  $k$ ,  $L$  is the total number of gray levels, and  $P_x(x_k)$  refers to the probability of the occurrence of a gray level  $k$ . This corresponds to Equation (4) in continuous images, which has the following discrete form:

$$y_k = T(x_k) = \sum_{j=0}^k \frac{n_j}{n} = \sum_{j=0}^k P_x(x_j) \quad (8)$$

The inverse transformation is:

$$x_k = T^{-1}(y_k), 0 \leq y_k \leq 1 \quad (9)$$

Histogram equalization (HE) is a simple and effective image enhancement method, but it suffers from global and excessive contrast enhancement. To overcome these problems, experts have developed two methods: adaptive histogram equalization (AHE) and contrast-limited adaptive histogram equalization (CLAHE). AHE can effectively enhance the detail information and reduce the over-enhancement of contrast by dividing the image into local regions and performing histogram equalization in each region. And CLAHE adds restrictions on contrast to AHE to avoid the problem of over-enhanced noise.

### 4.3 Adaptive Histogram Equalization

The AHE and CLAHE algorithms are methods that improve on the underlying histogram equalization algorithm. In this subsection, the basic principles of these two algorithms will be described in detail. For the input image  $X$ , the AHE algorithm transforms each pixel by calculating the histogram equalization transform function in a local neighborhood, Eq:

$$X'(i, j) = \begin{cases} f(i, j) + k(X(i, j) - m_{ij}), & 0 \leq X(i, j) \leq 255 \\ f(X(i, j)), & \text{other} \end{cases} \quad (10)$$

The gray level processed by the AHE algorithm is represented by  $X'(i, j)$  and  $X(i, j)$ ,  $w$  is a window of size  $m \times n$ ,  $m_{ij} = (1/(m \times n)) \sum_{i,j \in w} x_{i,j}$ , is the average of the gray values of  $w$ . The mapping function is  $f(\cdot)$

The AHE algorithm incorporates a domain histogram computation function for a single pixel to improve the brightness and contrast of the image. However, when the image pixel neighborhood is homogeneous, the neighborhood histogram may show a single-peaked distribution, which increases

the noise when mapped to the entire range of pixels. The AHE algorithm can be used to improve the quality of low-contrast images by adaptive equalization, but it is less suitable for images with a more homogeneous distribution of the neighborhood histogram.

The CLAHE algorithm imposes an upper bound on the histogram of the domain for each pixel, which effectively avoids the problem of excessive noise after processing by the AHE algorithm. For each segment, the histogram of each segment is obtained, and the number of pixels with equal gray values in the region is counted to calculate the CDF function, which is shown in (11):

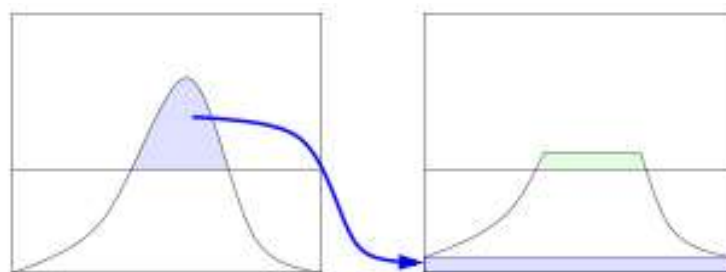
$$f_{i,j}(n) = \frac{N-1}{M} \sum_{k=0}^n (k) \quad (11)$$

M, N is the number of pixels in each region module, and its histogram  $h(k)$  is the representation of  $(i, j)$  region pixels

$k(k = 0, 1 \dots N)$  of. Each local cell can be cropped according to the cropping threshold  $\beta$ . The formula for  $\beta$  is:

$$\beta = \frac{M}{N} \left( 1 + \frac{\alpha}{100} (s_{\max} - 1) \right) \quad (12)$$

where (12) in Eq. is a cropping factor in the CLAHE algorithm. Figure ,6 shows the peak cropping and image redistribution.



**Figure 6.** Peak cropping and image redistribution map

During the application of the CLAHE algorithm, the input image is divided into a number of small regions of equal size, resulting in a significant block effect that may occur after histogram equalization of each region independently. In order to remove this effect, an interpolation method needs to be introduced to weaken the sense of demarcation between different regions and output a less noisy image. Bilinear interpolation effectively expresses the degree of correlation between individual pixels of the target image and their neighbors, and calculates pixel values based on this degree of correlation.

#### 4.4 AHE-CLAHE Algorithm

The disadvantages of the AHE algorithm are the possible introduction of noise and artifacts, while over-enhancement of certain regions may lead to loss of detail; while the disadvantages of the CLAHE algorithm include the possibility of artifacts and a relatively slow processing speed. To compensate for these drawbacks, the AHE-CLAHE algorithm combines the features of AHE and CLAHE. It avoids the noise and artifact problems caused by over-enhancement by limiting the degree of contrast enhancement for histogram equalization, and at the same time, it is able to enhance the local contrast of the image and improve the clarity of details. Therefore, in the field of image

enhancement, the AHE-CLAHE algorithm is able to better balance the local and overall contrast enhancement effects, avoid artifacts and noise, and have faster processing speeds compared to the CLAHE algorithm. Figure 7 shows the flowchart of AHE-CLAHE fusion algorithm.

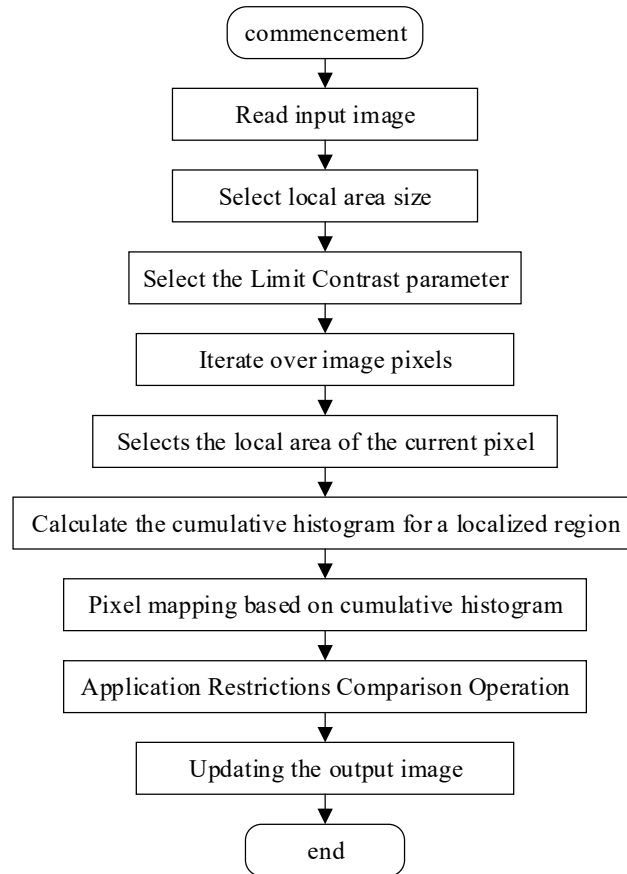


Figure 7. Flowchart of AHE-CLAHE fusion algorithm

#### 4.5 Test Results and Analysis

The original image as well as the images processed by HE algorithm, CLAHE algorithm, AHE algorithm and AHE-CLAHE algorithm were uploaded to Vuforia's official website for evaluation. Based on the evaluation results in Figs. 8, it can be seen that the original image receives two stars, the HE and CLAHE processed images receive three stars each, the AHE processed image receives four stars, and the image processed by the AHE-CLAHE algorithm receives five stars. Therefore, it can be concluded that AHE-CLAHE algorithm effectively improves the accuracy of image target recognition.

<input type="checkbox"/> Target Name	Type	Rating ⓘ	Status ▾	Date Modified
<input type="checkbox"/> AHE-CLAHE	Image	★★★★★	Active	Jan 04, 2024 09:29
<input type="checkbox"/> AHE	Image	★★★★☆	Active	Jan 04, 2024 09:29
<input type="checkbox"/> CLAHE	Image	★★★☆☆	Active	Jan 04, 2024 09:28
<input type="checkbox"/> HE	Image	★★★☆☆	Active	Jan 04, 2024 09:28
<input type="checkbox"/> Original	Image	★★☆☆☆	Active	Jan 04, 2024 09:15

Figure 8. Evaluation results

Figures 9 show the original image as well as the images processed using the HE algorithm, CLAHE algorithm, AHE algorithm and AHE-CLAHE algorithm.

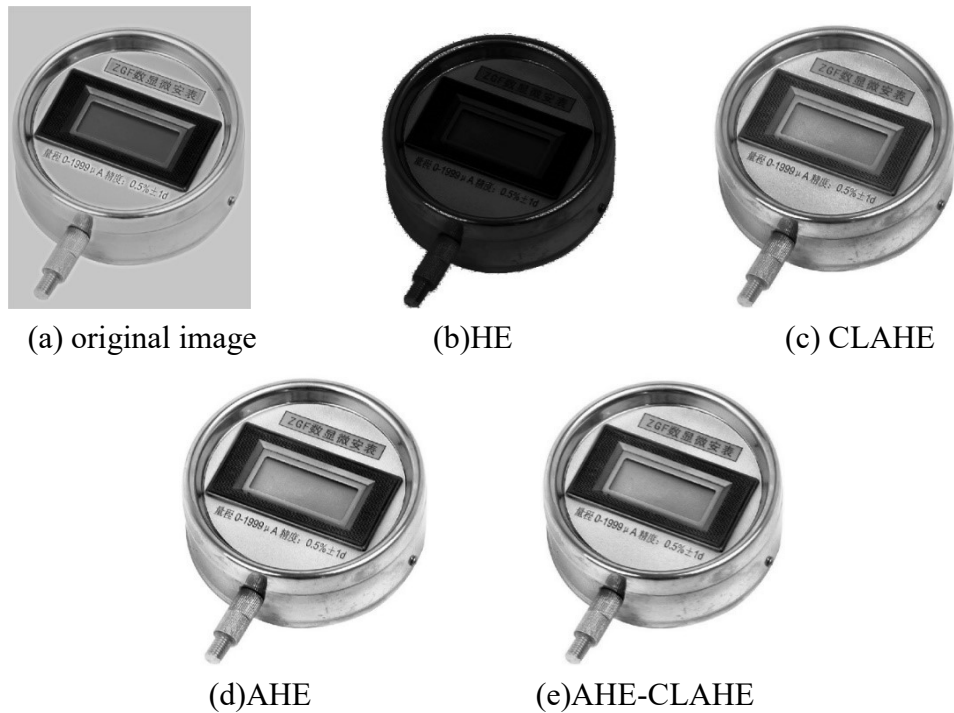


Figure 9. Image enhancement processing results

Vuforia is an image recognition engine. By using the "hide features" feature, you can view the image features detected and extracted by Vuforia's image recognition engine. These features can be labeled or visualized in some way to help observe their location and distribution in the image. By analyzing these feature points, it is possible to better understand how Vuforia finds key points in an image and extracts features. This is very helpful for optimizing image recognition algorithms, adjusting recognition parameters, and analyzing image recognition results. Figure 10 shows the evaluation results of using the hide features function to visualize the feature points.



Figure 10. Visualization of assessment results

## 5. Transformer Equipment Disassembly Function Realization

In order to gain a deeper understanding of the construction of the transformer, two modes of manual disassembly and predetermined path disassembly are realized in the virtual environment, and the logical framework of the disassembly function is shown in Figure 11.

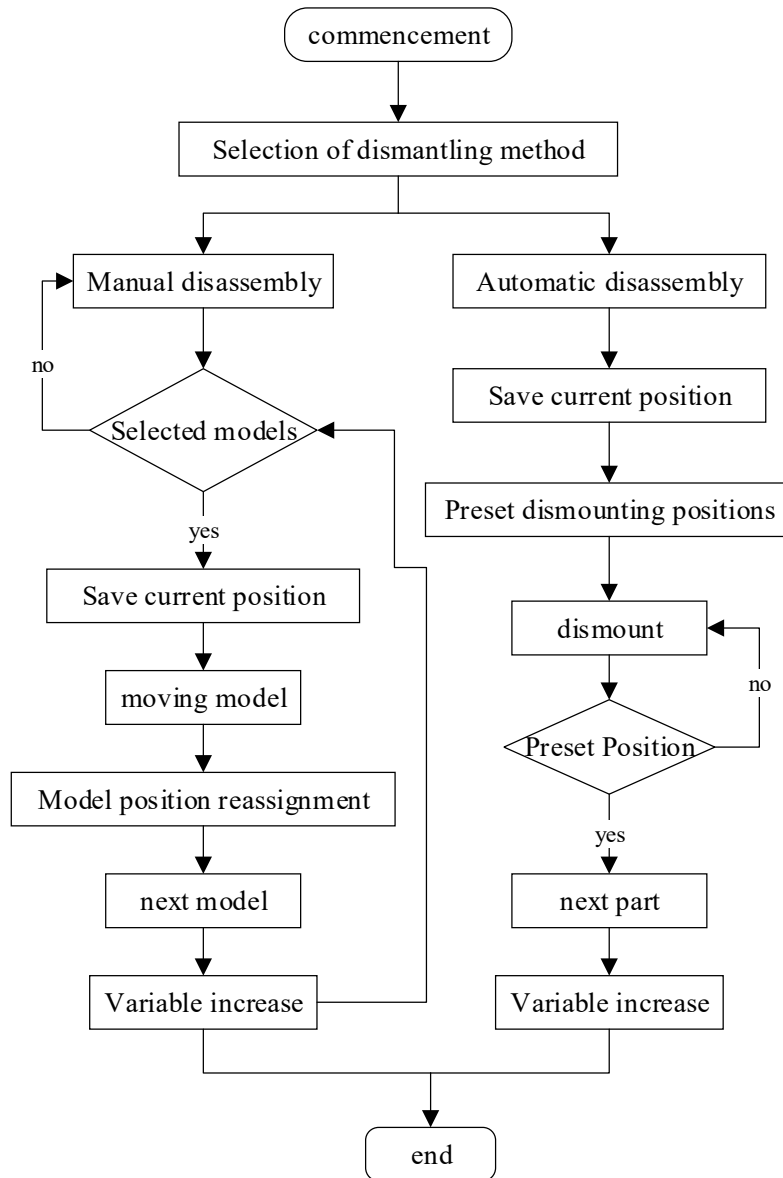


Figure 11. Virtual disassembly logic diagram

Manual disassembly refers to the function of picking up and putting back parts by left mouse click. The user completes the process of disassembly by manually clicking to select parts and move them to a specific location. This type of interaction is more intuitive and provides a good user experience, allowing the user to flexibly control the disassembly process. Automated disassembly is realized by preset paths and animation plug-ins. In automatic disassembly, the disassembly and assembly processes of parts are preset in advance. When the disassembly operation is triggered, the animation plug-in will automatically move and assemble the parts in the specified order and position according to the pre-set path and animation effects. This approach does not require the user to manually control the position of each part and completes the disassembly and assembly operation through an automated process.

## 6. Summarize

In this paper, an AR substation awareness APP is developed mainly based on the Unity 3D virtual engine and combined with the AR component AR Vuforia. The application realizes the function of displaying substation equipment models and enhances the recognition effect of the pictures by using the AHE-CLAHE algorithm. In addition, the function of equipment disassembly is also realized.

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