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Research on Virtual 3D Station based on Images

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Abstract: With the improvement of electric information, 3D visualization for the substation in the planning, designing, inspection, training and other aspects calls for a gradual increase. 3D rendering of the current technology is not yet mature, and equipment modelling is too complex, we propose a virtual 3D substation, which is an image-based system. The key issues include a sphere-based methods of fish-eye image mosaic, images of the plane and spherical mapping algorithm, a complete solution to achieve the system's construction, finally made some suggestions for improvement.

Keywords: Sphere surface mapping, panoramic image mosaic, virtual 3D substation, image-based panoramic

1. Introduction

Image-based virtual 3D system is also known as 360-degree panoramic, which is a branch of the virtual reality field. It's on the basis of realistic photos, and then through the complex computer processing to generate the output of a realistic 3D vision. People can interact and experience the virtual world with the help of mouse and keyboard. Therefore, the virtual 3D system, in essence, is a whole new fashion of visualization of the operation and interaction of complex data through the computer. Compared with the traditional man-machine interface, as well as the popular Windows operating, virtual 3D systems has been a qualitative leap in the technical thinking.

Image processing is a hot area of research, and many researchers are working in the area. Literature 1 incorporated the statistics of natural images into Bayesian models to illustrate image processing in colorization of gray images, compression of color images and reconstruction of chrome channels from corrupted data [1], Zhang proposed a novel image classification model based on contourlet transform and dynamic fuzzy graph cuts [2].

Image-based virtual 3D system was mostly for the display of the environment and streetscape. Google Street View technology has been introduced in the literature 1, and the keys of the streetscape in the production process such as data acquisition, image processing, building 3D and 3-D Virtual Tour are also described [3]; Yan and others catch the characteristics of image-based virtual reality technology and analyzed the tourist attractions web site to establish the feasibility and effectiveness of the 3D panoramic exhibition. They also elaborated a panorama generation principle and the realization of 3D virtual space scene, and finally achieved the system combined with the Yunnan Stone Forest world Geological Park system [4].

The main content of virtual 3D system contains: image registration, image projection, scene change, and so on. Literature 5 suggested an automatic and precise image registration based on phase-correlation combined with surface fitting [5], Wang studied the 2D supervised discriminant projection method for feature extraction [6], Lee raised effective scene change detection by using statistical analysis of optical flows [7].

With the improvement of the level of information technology, the substation planning, design, inspection and training has increased the requirements of 3D visualization. Cai proposed the substation anti mistaken operating system through the way of real-time identification of signs, thus positioning the operator of the substation [8]; literature 4 uses 3D modeling software 3Dmax as the development platform, and gives a brief

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overview of the substation and its devices, then it analyses the application of 3Dmax in the 3D design of substations and improving design efficiency which contains the details of the methods, the paper realizes the mapping of virtual and reality in substation design [9]; Feng use 3D modeling software and virtual develop platform to build a virtual reproduction of the complex underground substation running environment characteristics of underground substations. It carry out simulator training for the students of underground substation such as daily patrol, operation and accident treatment etc according to the characteristics of underground substations [10].

Throughout the 3D visualization substation construction process that utilizes the traditional virtual reality and 3D GIS technology, there are many kinds of problems. For example, 3D graphics rendering technology is not mature; the effect of 3D browse is not beautiful; the process of equipment modeling is complicated and needs a great amount of data; system construction cycle takes so long a time, which is also difficult to maintain. In this paper, we put forward applying Image-based of virtual 3D technology to the transformer substation 3D visualization construction. It can not only enhance the rich visual experience of users, but also create a more intuitive way to interact with computers. Finally this pattern substantially boosts working efficiency.

2. Key Technologies

3D panorama belongs to virtual reality field, which is a new 3D experience model. The core content of it is to make correction and joining of the images taken at various angles to form a panoramic image that contains the point of view of all visual information, and then take some conversion algorithm to set up a virtual 3D scene with 3D visual experience. The ripe 3D panoramic system conversion algorithm is mainly divided into two types: cube mapping and sphere mapping. Sphere mapping is based on the theory of shooting around the visual information concentrated in a sphere, so the panoramic image formed by splicing is essentially spherical to flat mapping. And then make the inverse mapping of panoramic image following the same theoretical plane to the sphere, by this means we can form a virtual 3D scene of the shooting with 3D visual experience. The theoretical basis of the cube maping is to imagine the space all around into a cube, so shooting the cube, and then get the panoramic images of the formation of the cube is the cube surface mapping of the plane. By the same process of inverse mapping we can reduction 3D visual information. Therefore, we can easily find that the sphere mapping algorithm is applied to the vast scene of visual space and cube mapping applies to the narrow place in the space. Take care of the characteristics for the substation and the requirements of virtual 3D substation system application, we chose the sphere mapping to accomplish 3D mapping.

2.1. Sphere plane mapping

Fish-eye image correction and flat panoramic image of the 3D rendering will involve in the mutual mapping of the sphere coordinates and plane coordinates. The following shows the establishment of the XYZ coordinate system of the sphere and the UV coordinate system of the plane, so that we can conduct the study of both the mutual mapping algorithm [11].

Principle 1: UV coordinate system: we use the lower-left corner of the graphic image for the point (0,0) to finish establishment of the UV coordinate system, take U-axis along the direction of image width and height direction for the V-axis, make the lower-right corner of the image as (1,0) point and the upper-left corner of the image as point (0,1). The U-coordinates of the point A on the image is the ratio of horizontal distance between the point and the image left edge and the and the image width coordinates stands for the ratio of the vertical distance between the point and the lower edge of the image and the height of the image, so U and V values must be between 0 and 1.

Principle 2: XYZ coordinate system: take its center point as the origin point (0, 0, 0) of the coordinate system and R as radius to establish sphere coordinates.

Principle 3: mapping of the XYZ coordinate system and the UV coordinate system: take (0,-R, 0) as a starting point and (0, R, 0) as the end point, the Semicircle along the direction of the sphere for the V-axis, the U-axis where the former point (x, y, z) on the V-axis take the point (R, y, 0) as the starting point and the end point, which is a counter clockwise direction circle, shown in Figure 2.1.

So we have established the mapping relationship that allows the points on the plane image and the points on the mapping sphere correspond with each others. This is the theoretical basis of mapping sphere and plane. Sphere mapping depends on the rules with the UV mapping rules when the panoramic image is generated. Fish-eye image correction means mapping the point of the sphere to the plane, while the rendering of 3D scene is to map a pixel of the any location of the plane image, in accordance with the same UV mapping inverse mapping to the sphere, then the image formed on the sphere will produce 3D visual experience. Because the sphere mapping to the plane and the plane mapping to the sphere is mutually inverse process of the same rules, so this article describes only the plane to the spherical mapping process. This algorithm represents the mapping process of point A(x, y) on two-dimensional image to the $A'(x', y', z')$ on sphere.

(1) Take an arbitrary point A (x, y) of the image in the plane coordinate system to calculate the UV coordinates of the point A:

$$A_u = \frac{x}{w}(w : the\ width\ of\ the\ image) \tag{1}$$

$$A_v = \frac{y}{h}(h : the\ height\ of\ the\ image) \tag{2}$$

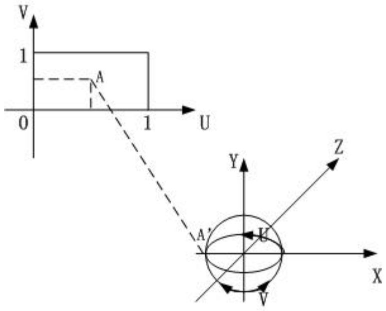

Figure 2.1: mapping of plane and spherical

(2) A point is mapped to the sphere with the same UV coordinates of point A'. A' point of $U \to V$ coordinates is the (Au, Av). Under the relationship of UV coordinate system and the XYZ coordinate system described in 2.1, the y coordinates of A' is:

$$y' = -\cos(A_v \times \Pi) \times R \tag{3}$$

And the circle radius of the U-axis of A' point:

$$r = \sqrt{R^2 - y^2} \tag{4}$$

The x coordinates and z coordinates of point A':

$$x' = r \times \cos 2\Pi \times A_u \tag{5}$$

$$z' = r \times \sin 2\Pi \times A_u \tag{6}$$

In fact, the fish-eye panoramic photos are formed on the basis of the inverse process; the pixel of the ball surface is mapped to the two-dimensional image. Therefore, according to this algorithm the process that the panoramic image mapping plane to the spherical, will restore the 3D visual information in the shooting.

2.2. Panoramic image mosaic

A key technology of implement of 360° panoramic view is image stitching. Research based on image stitching is now becoming mature. Shao found a variety of image registration algorithm through the study of image stitching algorithm suitable for different environments from basic image stitching technology research, which can used to improve the efficiency and accuracy of the image mosaic [12]; Zhang used the shape feature analysis techniques, in order to reduce the amount of computation of the traditional matching algorithm based on gray scale, and then formed a new template matching algorithm [13].

Panoramic image mosaic mentioned in this article based on the following basis:

Equipment: SLR camera, fisheye lens, tripod, panorama head;

Shooting methods: fix SLR cameras; rotate it along the longitudinal axis of the tripod to ensure that the same imaging centers shoot 3-6 fish eye in photos with the equal angle.

The panoramic image stitching algorithm is as follows:

(1) Make the fish-eye image 3D. Extract the effective circular area of the fish-eye photo, calculate the 3D spherical coordinates of any point (x, y) on fish-eye picture according to the equidistant imaging model, and map the fish eye photo to the sphere with the radius of the focal length f.

(2) Match the similar warp . Two adjacent fish-eye images match the sphere warp direction to generate a similar warp.

(3) Fuse the sphere image . Integration of images uses the way that fade-out. That means the overlap region in the mosaic image slowly transition from the first image to the second image, thereby maintaining the consistency of the mosaic image in the visual.

2.2.1. Fish-eye image 3D

The fish-eye lens is an ultra wide-angle special lens that can be close to or over 180 degrees of viewing angle. It can accommodate a wide viewing scene because of the wide angle. But the straight line around the screen will be curved. Only the straight line on the center part of the lens can be maintained its original state. As shown in Figure 2.2, the effective pixels of the fish-eye photo are the center circle.

Figure 2.2: Original fish-eye image

This topic is based on the following assumptions: the distance between imaging points in the field of view and the focus of the lens is equal; the fish-eye's imaging of horizontal and vertical viewing angles are all 180°. So the effective part of the fish-eye image mapped to the sphere is a hemisphere, the outline of the fish-eye image is the hemisphere's section round; the center is the vertex of the hemisphere, as is shown in Figure 2.3.

Create two-dimensional Cartesian coordinate system with the fish-eye image pixels. The center O, radius R, the coordinate system and the image point of intersection A, B, C and D. Establish the 3D coordinate system with the Sphere to be mapped, the center of the sphere O', the radius of R. Circular outline of the fish-eye image

OABCD, the mapping points is cyclotomic field $O'A'B'C'D'$ of the XOY plane and $'$ sphere. After mapping, the mapping point of the point O on the sphere is $O''(0,0,R)$, mapping points of point (R, 0), (0, R), C(-R, 0), (0,-R) on the sphere are $A'(R,0,0)$, $B'(0,R,0)$, $C'(-R,0,0)$, $D'(0,-R,0)$.

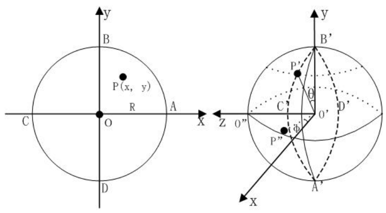

Figure 2.3: Fisheye image mapped to the sphere

The mapping point of arbitrary point P(x, y) on fish-eye image is $P'(x,y,\sqrt{R^2-(x^2+y^2)})$. P' point and the Y-axis positive angle is θ, the projection of P'on XOZ plane is P'' and the X-axis positive angle with P'' is φ.

$$\theta = \cos^{-1}\frac{y}{R} \tag{7}$$

$$\phi = \tan^{-1}\frac{z}{x} = \tan^{-1}\frac{\sqrt{R^2-(x^2+y^2)}}{x} \tag{8}$$

On this grounds, after the accomplishment of mapping, the point on the image can be expressed as (θ,φ), namely $(\cos^{-1}\frac{y}{R}, \tan^{-1}\frac{\sqrt{R^2-(x^2+y^2)}}{x})$, where:$\varphi \in [0,\Pi]$

2.2.2. Registration of similar longitude line

Registration of similar longitude line is on the basis of the projection ball to find the two images match position in the warp direction of image-based similarity distance, thus completing the image registration work. The original fisheye images to be spliced mapped to the same radius of the sphere surface in accordance with the method of 2.2.1,shown in Figure 2.4. Specific alignment principles are as follows:

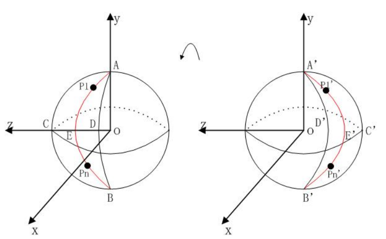

Figure 2.4: Fish-eye image registration

(1) Select one longitude line of registration Figure (referred to Figure a) $\varphi = \varphi 1$, using the Harris corner detector to extract the feature points [14],to get the gray corner sequence $P1, P2, \ldots Pn$, corresponding to the coordinates $(\theta 1,\varphi 1)$, $(\theta 1,\varphi 1)$, ...$(\theta n,\varphi n)$;

(2) Set the effective pixel area diameter of fish-eye image is L, then after the mapping the effective number of lines is L. Deal with approved plans (referred to Figure b), take φ is $= \varphi' = k\Pi/L$, $(k \in [0,L-1])$, were calculated similar distance between the longitude line k in Figure b and $\varphi = \varphi 1$longitude line in Figure a. As the following equation (9), which SimiD is the similarity distance between two longitude line, $Y1(\theta 1,\varphi 1)$ is the gray value at the point $(\theta i,\varphi 1)$ in Figure (a), $Y2(\theta i, k\Pi/L)$ is the gray value of point $(\theta i, k\Pi/L)$ in Figure b .Gray value can be derivate to use image RGB value based on the equation shown in (10).

$$SimiD(1,k) = \sum_{i=1}^{n}\frac{|Y_1(\theta_i,\phi_1) - Y(\theta_i,k\Pi/L)|}{n} \tag{9}$$

$$Y = 0.299R + 0.587G + 0.114B \tag{10}$$

(3) Take $\varphi = \varphi k = k\Pi/L(k \in [0,L-1])$. Repeat the above steps (1) and step (2), until to calculate out similarity distance of any two longitude line of two fish-eye. Take three pairs of longitude line which has the smallest of all similar distance.

Based on the shooting, we choose the same point, the same angle to shoot three photos for an example of how to select the matching longitude line.The horizontal viewing angle of each photo is 180°, so the region of overlap angle is$180° * 3 - 360° = 180°$.AS isometric rotation shooting each overlap region is approximately $60° = \Pi/3$, so if $|\varphi + \varphi'| \approx \Pi$, it is the matched longitude line to be selected.

2.2.3. Sphere image fusion

After registration of similar longitude line is completed, we calculated out the best registries longitude line. Then we can achieve the seamless mosaic of two images. We use the spherical rotation to complete fusion, shown in Figure 2.4.The red line indicates the matched longitude line of the two spheres. By counterclockwise rotation of the image side of the Figure b until coincide with the matched longitude line of the Figure a, overlap to take the weighted average gray value of point to complete the smooth processing.

Fish-eye images have the feature of more edge more serious of distortion. So take the matched longitude line as the center, in both directions weighted average. The overlapping part of the counter-clockwise, the original images (a) deformation smaller, so the weight greater weight, while the clockwise overlap, matching images (b) small deformation, greater weight.

Take three photos with the same point and the same angle for example, the overlap region around$\Pi/3$,take$\mu = 1 - \frac{\phi - 2\Pi/3}{\Pi/3} = 3(1-\phi/\Pi)$,weights of the overlap region

,most left edge of image a is $\mu = 1$, weights of image b is $\mu = 0$, at the central longitude line the weights of the image a and image b is equal to 1/2, the most right edge of the image of the overlap region weights is $\mu = 0$, weights of image b is =1, an image fusion algorithm is as follows (11) shows, where $\theta \in [0, \Pi]$, $\varphi \in [2\Pi/3, \Pi]$.

$$Y(\theta,\phi) = Y_1(\theta,\phi) \times \mu + Y_2(\Pi - \theta,\phi) \times (1-\mu) \quad (11)$$

3. Case of the Implementation

Image-based virtual 3D substation consists of three parts, release of 3D panoramic view, virtual 3D interaction and system integration, architecture was shown in Figure 3.1.

3.1. Release of 3D panoramic view

The release of 3D panoramic view includes data preparation, fish-eye image correction, and generation of panoramic images.

The data preparation contains a fish-eye image data, shooting point spatial data and configuration data. Fish-eye image data according the shooting method in accordance with 2.2 in the substation, to form all 3D visual information of shot point 360 degrees to generate image data, as shown in Figure 3.2; shooting point space position data is generated by GPS positioning of each shot point; configuration data contains navigation data between the scenes, as shown in Figure 3.3, as well as users and devices interact essential data (virtual operating switch status data, etc.).

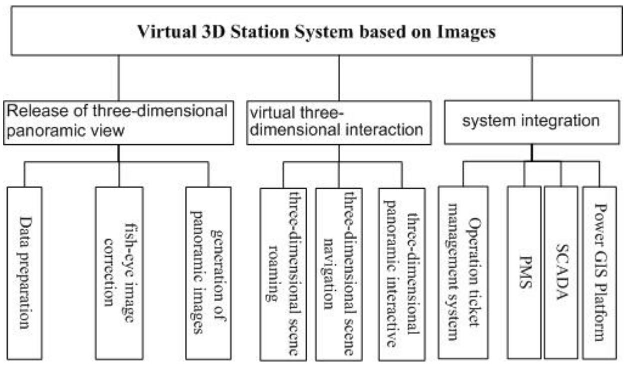

Figure 3.1: System structure

Panoramic image stitching is completed by using 1.2 sphere-based image map and mosaic method, after splicing using 1.1, the mapping method of the sphere plane to map the spherical image to the plane. Then use a common image correction tools for the late processing, the effect shown in Figure 3.4.

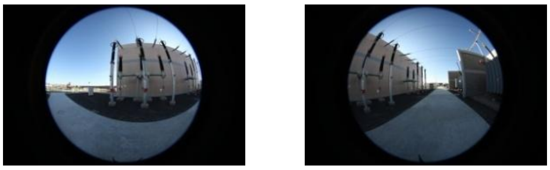
Figure 3.2: Original fish-eye image

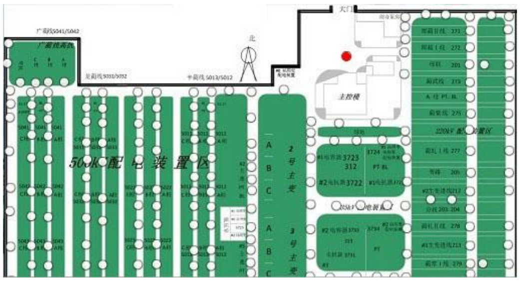
Figure 3.3: Substation patrol chart

3D panoramic configuration is divided into a conventional panoramic image managementpanoramic view of the object management and 3D scene information management. Conventional panoramic image management does seamless deal for image data and then label the device contained in the image. The panorama object management does the image 3D treatment on the key equipment, to establish the association with the 3D scene, convenient device interaction. 3D scene information management configure geographic data of each 3D scene and attribute data, and process the location and scene, according to the partial data of shooting points to establish the association of the 3D scene with the power of GIS.


Figure 3.4: Panoramic image expansion

3.2. Virtual 3D interaction

Virtual 3D interaction contains 3D scene roaming3D scene navigation and 3D panoramic interactive.

3D scene roaming id based on conventional panoramic images released in the 3.1. Using 2.1 sphere plane mapping algorithm to map plane image to the sphere surface. Through the 3D rendering technology, display 3D real sphere image. By rotation operation of the sphere, achieve 3D roaming and the perspective changes. By changing the size of the sphere, achieve the scaling of the current scene, and ultimately to simulate a real 3D effect.

3D scene navigation is based on the substation patrol chart, or GIS picture to establish the correspondence between the point and 3D scene. Through the map navigates to switch between any scene, the other 3D scene in the direction of instructions, can switch between adjacent scenes. System has line patrol functions, automatic navigation between the sequences of scenes can be achieved by pre-righteousness patrol line.

3D panoramic interactive establish the unique identifier of the device object with 3D panoramic configuration information collected on 3.1. Through contact with the various systems to achieve the following interaction: establish the interaction of the equipment and the SCADA system to display real-time operating data of the equipment; establish the communications between equipment and production MIS system; By real-time data analysis and historical data mining, provide production and decision support; operating the virtual 3D objects of the equipment, switch real-time state of the equipment and operating processes of rehearsal, to provide support for operating ticket management system.

3.3. System integration

Image-based substation virtual 3D system provides the virtual 3D services for the power industry. Through the integration of other power enterprise information systems, such as operating ticket management system, production and MIS systems, scheduling SCADA systems, electric power GIS platform to form a new platform which is a unified management enterprise data.

Integrated with image-based substation virtual 3D system will greatly enhance the visualization of operating ticket management system. After integration, the role of the wiring diagram will no longer be the site of billing, but the navigation panel between the different devices. Through the navigation interface of image-based Virtual 3D system, the scene is navigated to the device. In which the device layer will display the equipment operating panel and its attribute data which the user can operate. Operation panel will be constructed in accordance with the actual situation of the equipment to simulate a real 3D device operating panel, so that the user's virtual operation more intuitive. Ultimately improve the accuracy of the billing operation to ensure the personal safety of operating personnel in the field, and enhance system security.

Integrated with image-based substation virtual 3D system, all types of power information systems, such as the production and MIS systems, scheduling SCADA systems will have better visualization capabilities and on-site visual experience. Integration can enhance the asset management of grid equipmentoperation and management and regulatory capacity, can provide decision support for the economic operation of the gridcondition assessment and development planning.

Integrated with image-based substation virtual 3D system, the power GIS platform on the basis to meet the current two-dimensional GIS needs improve an increase effect of 3D display. And this 3D presentation not only needn't time-consuming operation such as complex prior 3D model, but also includes all the visual information. Enhanced by the integration GIS platform in the power industry, while improving the safe operation of electrical hazards and normative.

4. Conclusions

This paper analyzes the imaging principle of the fish-eye lens, provide a fish-eye image stitching method based on the sphere, research on plane and spherical image mapping algorithm, and ultimately develop the image-based substation virtual 3D system. The system uses image processing technology to splice the fish-eye images collected, and form the 3D landscape of the substation field scene by the processing of 3D scene. The goal of the system was to improve equipment and scene visualization, allowing decision-makers through a virtual operation to complete the switch of the device status. Through integration with other systems to provide decision makers with the auxiliary function. But there are some areas for improvement for the system:

(1) During the panoramic image mosaic algorithm implementation processing, it is based on certain assumptions to simplify and improve the image capture process. The next step should be to improve the robustness of the system;

(2) The System has a simple discussion of 3D process of equipment in the scene. The 3D model of the standard equipment can be achieved. The next step should be integrated infrared distance and point cloud monitoring technologies.

(3) Navigation between the 3D scene is actually two shooting scenes switch between the points. It's not coherent. The next step should be considered to achieve a continuous scene change.

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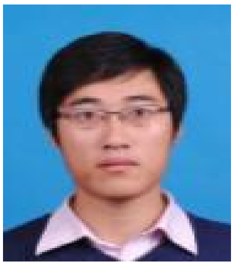

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