A Visualization Automated Analysis and Evaluation Method Based on Virtual Reality

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Abstract. To ensure products with high reliability and quality, maintainability design and verification is an integral part of design process.

As a crucial factor in maintainability design, visibility evaluation is the most important part of maintainability design and verification. However, subjective and expert judgment in evaluation methods are the two major problems limiting the development and application of the visibility design. To solve these problems, this paper proposes a visibility automation analysis and evaluation model based on virtual maintenance. Firstly, two sub-evaluation indicators are designed for visual ability and visual obstruction. Secondly, in responds to the two indicators, two models are established based on visual cone and feature points respectively. Moreover, a comprehensive visual accessibility evaluation model based on line-of-sight interference detection and two models is developed. Finally, a case of an engine coupling fastening bolt visibility assessment is conducted and verifies the effectiveness of the proposed method.

1. Introduction

At present, with the increasing level of automation and intelligence in large-scale equipment equipped with high reliability and quality characteristics, maintainability design and verification have become an indispensable research area in the equipment design process[1]. Currently, virtual reality technology can already be applied in creating a virtual space that includes maintenance personnel, maintenance tools, 3D digital prototypes, and maintenance processes. In this space, it is possible to simulate the equipment maintenance process, provide strong support for the analysis and evaluation of equipment maintenance visibility, detect the lack of equipment maintenance design in advance, and put forward suggestions for improvement [2]. Zhang Yuantao and Wang Zhanhai studied a CATIA-based visual field analysis function, and visualized the target object's visual accessibility by superimposing the left-eye and right-eye cones as the binocular visual area[3 , 4]. Yang Chunhui and others used the quality function development and evidence theory method to construct the evaluation index system of each component, and obtained the quantitative evaluation level of visual accessibility of complex equipment[5]. However, the maintenance personnel currently use the virtual reality technology based on maintenance evaluation method to subjectively evaluate the virtual maintenance process, unable to provide objective data to support the evaluation results, rely on expert experience, and lack of objective, quantitative, and comprehensive evaluation methods. Therefore, how to rely on virtual maintenance technology to study how to achieve accessibility automated analysis and evaluation has become the key to improving the design level of equipment maintenance. This paper firstly establishes a visualized automated analysis and evaluation model, and conducts in-depth study on two sub-evaluation indicators: line-of-sight accessibility and visual occlusion barrier. The visible cone-based visual model and the feature point-based visual occlusion evaluation model are studied. Based on the above, a visual comprehensive evaluation model based on the line of sight interference detection was established to realize visualized automated analysis and evaluation. This part of our specific discussion will be discussed in the second part. The verification of the case will be discussed in the third section. The conclusion will be discussed in the fourth part.

2. Methodology

This section first analyzes the two indicators of the evaluation of visual accessibility design, the line-of-sight accessibility and the visual occlusion barrier. The visual cone-based sight accessibility model and the visual occlusion barrier model based on feature points are proposed separately for the two indicators, on the foundation of which, a visual comprehensive evaluation model based on line-of-sight interferometric detection realizes visualized automatic analysis and evaluation of maintenance operations. The methodology process is shown in Fig 1.

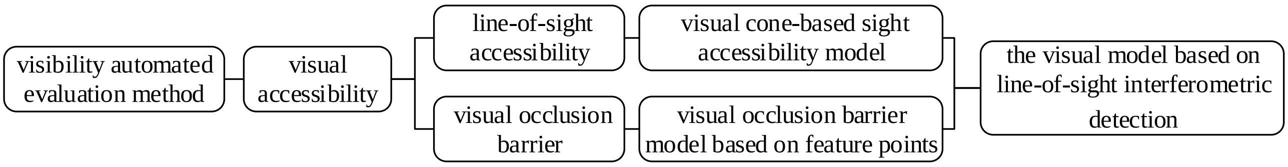


Figure 1. Visibility automated evaluation method research process

2.1 *Evaluation*

Good visibility requires equipment maintenance personnel to maintain a natural and comfortable view of maintenance components that are not obstructed during maintenance operations[6]. According to the basic principles of visual design and data information in the virtual maintenance environment, the visual accessibility is divided into two aspects: the line-of-sight accessibility and the visual occlusion barrier.

1) Line-of-sight accessibility

Line-of-sight accessibility refers to whether the repair parts are within the field of view of the maintenance personnel during maintenance. Line-of-sight accessibility is the basic requirement for maintenance operations and relates to maintenance safety incidents[7].

2) Visual occlusion barrier

Visual occlusion refers to the condition of maintenance parts that cannot be accurately observed by maintenance personnel because of obstructions caused by maintenance parts or environmental parts during maintenance. Visual obstruction causes maintenance personnel to operate blindly, which may lead to maintenance safety.

2.2 *Visual cone-based sight accessibility analysis and evaluation model*

In terms of line-of-sight accessibility, coordinate transformation is first carried out. Based on the maintenance personnel's visual field model, the coordinate information of the maintenance component feature points in the virtual environment coordinate system is converted into the visible cone coordinate system. Secondly, by assessing whether the visible feature point is within the field of view of the maintenance personnel, the sight-accessibility design of the maintenance component is evaluated.

2.2.1 *The mathematical model of the maintenance personnel's field of vision*

According to the provisions of the scope of maintenance, maintenance personnel visual cone can be regarded as an elliptical cone approximately[8], with the middle point of sight of two eyes as the origin O of the coordinates, the vertical direction of the visual field is the x-axis, the horizontal direction of the visual field is the y-axis, and the normal line of sight is the z-axis. In the cone coordinate system O, the parametric Equation(1) is established for the maximum visual field of maintenance personnel:

$$[x_0, y_0, z_0]^T = [0.7002u \sin v, 0.5774u \cos v\,, u]^T \tag{1}$$

The length of the line of sight is the angle between the line connecting the point on the visible cone and the point of view and the Y axis.

2.2.2 *Change matrix*

Since the data information in the virtual maintenance environment is based on the world coordinate system of the entire virtual environment, the virtual human visual cone model is established in the virtual visual cone coordinate system, so a homogeneous transformation matrix of virtual world coordinate system A to visible cone coordinate system O is given by Equation(2):

$$\mathrm{T} = \mathrm{R(B)} \times \mathrm{R(O)} \tag{2}$$

$\mathrm{R(B)}$ represents the position and attitude transformation matrix of the virtual environment coordinate system A with respect to the virtual maintenance personnel coordinate system B, and Equation(3) is given in combination with the three maintenance postures during maintenance.

$$R(B) = R_x(\theta) \times R_y(\phi) \times R_z(\varphi) \times T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\phi & 0 & -\sin\phi & 0 \\ 0 & 1 & 0 & 0 \\ \sin\phi & 0 & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\varphi & \sin\varphi & 0 & 0 \\ -\sin\varphi & \cos\varphi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ T_X & T_Y & T_Z & 1 \end{bmatrix} \quad (3)$$

Wherein, $R_x(\theta)$ indicates that the coordinate system A is rotated by θ degrees around the X axis with respect to the coordinate system B, and $R_y(\varphi)$ indicates that the coordinate system A is rotated by φ degrees around the Y axis with respect to the coordinate system B, $R_z(\phi)$ indicates that the coordinate system A is rotated by ϕ degrees around the Z axis with respect to the coordinate system B. Degree angle, the offset matrix of the origin of the R(O) table coordinate system A in the coordinate system B.

R(O) represents the position and attitude transformation matrix of the maintenance personnel coordinate system B with respect to the visible cone coordinate system O.

2.2.3 *Mathematical model based on visual cone for sight line accessibility analysis and evaluation*

The coordinates of the maintenance component feature point in the visible cone coordinate system O can be obtained through coordinate transformation. If the content is satisfied in the visible cone Equation(4), the

$$(x_i/0.7002)^2 + (y_i/0.5774)^2 \geq z_i^2 \quad (4)$$

feature point is located in an invisible region; otherwise, it is located in the maximum visual field region.

In the virtual environment, maintenance component information, virtual person information, and virtual environment information can be obtained. The coordinates are transformed into the visual cone coordinate system, and the coordinates of the maintenance component feature points are substituted into the visual cone equation, so that whether or not each point is located in the maintenance personnel can be obtained. Within the visible range. When all the feature points are located in the visible cone of the maintenance personnel, the line-of-sight accessibility of the maintenance part is well-designed, otherwise it is not qualified.

2.3 *Visual occlusion barrier evaluation model based on feature points*

The evaluation mathematical model firstly extracts the features of the 3D mesh model of the maintenance parts and obtains the collection of the feature points, which is represented byQ_i. The Q_a are the visible feature points of the maintenance parts, and the occlusion of the feature points can be classified into two categories: (1)The feature points Q_b are occluded by maintenance parts themselves, (2) The Q_c are occluded by other maintenance parts in the virtual environment, and the maintenance personnel cannot see it. The Maintenance parts visual obstruction diagram is shown in Figure 2.

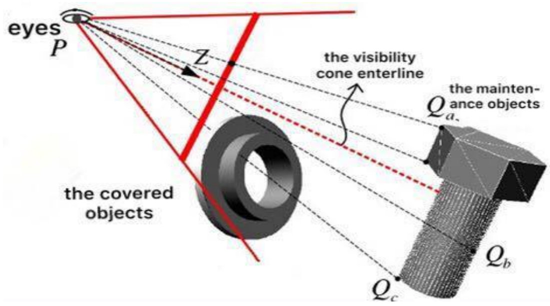


Fig 2. Maintenance parts visual obstruction diagram

2.3.1 *Principle of algorithm*

(1) Construct the parametric equation of sight. Set(x_0, y_0, z_0) as the starting point of the line of sight. Calculate the direction vector of the line of sight(x_d, y_d, z_d) through the coordinates of the feature point and the coordinates of the point of sight. And the sight(x_0, y_0, z_0)should satisfy Equation(5).

$$x_d^2 + y_d^2 + z_d^2 = 1 \quad (5)$$

The parametric equation shown in Equation (6) shows the line of sight emitted by the point:

$$\begin{cases} x = x_0 + x_d \times t \\ y = y_0 + y_d \times t \\ z = z_0 + z_d \times t \end{cases} \tag{6}$$

(2) AABB Axial Bounding Boxes for Constructing Shading Parts. In various bounding box technologies, the calculation of building the AABB bounding box of the masking component model is very simple, and it is only necessary to calculate the maximum and minimum values of the x-coordinate, y-coordinate, and z-coordinate of each feature point. The feature points of the occlusion part model extracted by the above algorithm are applied to obtain the feature point set FB of the model. Traverse the FB to calculate the maximum,x_{max},y_{max}, $z_{max}$the coordinates, the minimum x_{min},y_{min}, z_{min} the coordinates, respectively, to construct the AABB bounding box of the model.

(3) Determine if the line of sight intersects the AABB bounding box. Equation(7) represents the plane P,

$$\mathrm{AX} + \mathrm{BY} + \mathrm{CZ} + \mathrm{D} = 0 \tag{7}$$

substituting the line-of-sight parametric equation, so that Equation(8) can be obtained.

$$\mathrm{t} = -\mathrm{b}/\mathrm{a} \tag{8}$$

When a=0, the line of sight is parallel to the plane; if t<0, the corresponding point of intersection is not on the line of light, and the intersection is invalid. Substituting the value into (6) yields the coordinates of the intersection.

(4) Determine if the intersection is on the surface of the bounding box. Although there is an intersection between the line of sight and the bounding box plane, it does not necessarily fall within the rectangular space surrounding the box surface. Determine whether the intersection point is in the axial bounding box. Compare the $x_i, y_i and\ z_i$ value of the coordinates of the vertex with the maximum x_{max}, y_{max},andz_{max} the coordinates, the minimum x_{min}, y_{min} and z_{min} , and the coordinates respectively. If $x_{min} < x_i < x_{max}$ $y_{min} < y_i < y_{max}$and$z_{min} < z_i < z_{max}$ are both true, the intersection is in the bounding box.

2.4 *Visual accessibility automated analysis evaluation model*

The main steps of automated visual assessment of visual accessibility are as follows:

(1)Acquire virtual human data, virtual prototype data, visual obstruction data, and extract feature data;

(2)Establish a mathematical model of maintenance personnel's field of vision to determine the sight accessibility of maintenance parts;

(3)Acquire the current viewpoint position, and construct the line-of-sight parameter equation according to the data of the repair component feature point;

(4)Construct the AABB bounding box of the visual masking component according to the set of obstacle feature points;

(5)Iterate through the eight surfaces of the bounding box, check whether the line of sight intersects the plane where the bounding box surface lies, and check whether the intersection point is within the bounding box surface rectangle. If the intersection point is within the range of the surface rectangle, it means that the component blocks the line of sight and stores the feature point in the collection; otherwise, it continues to judge other feature points;

(6) The above algorithm can be used to judge the occlusion detection result of the viewpoint for a certain feature point. According to the maintenance visual accessibility design criterion, if all visible feature points that are not occluded by itself are not occluded by external objects, the maintenance component visual accessibility is well designed. If the collection L_N not empty, it means that the maintenance part is not visible under the current visual angle, and the visual accessibility design of the maintenance part is unqualified; if the collection L_N is an empty set, the visual accessibility of the maintenance part is well designed. Visual accessibility automated analysis and evaluation process is shown in Fig 3.

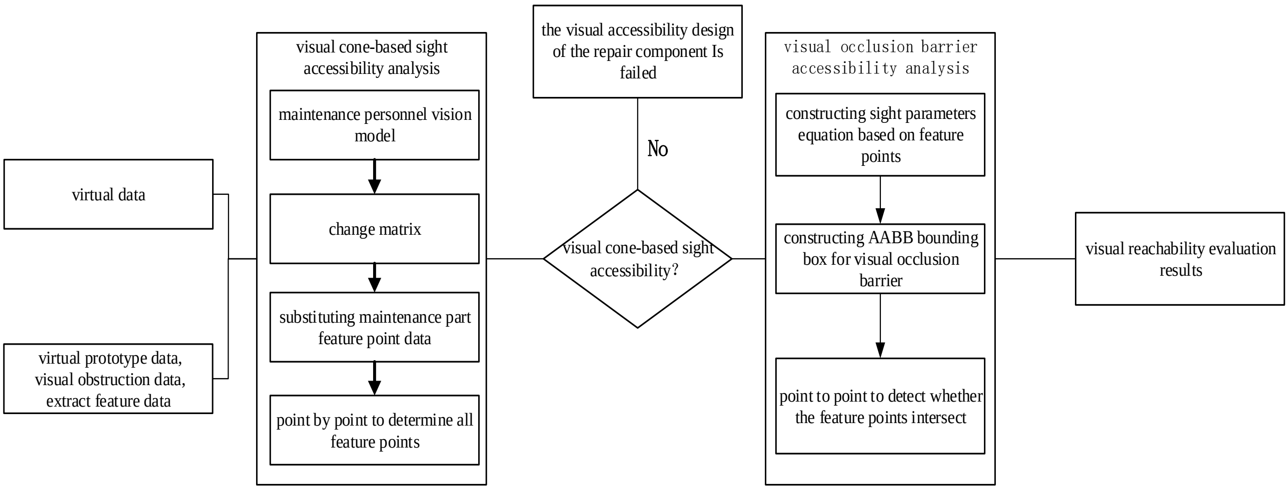


Figure 3. Visual accessibility automated analysis and evaluation process

3. Case analysis

This chapter selects a fastening bolt on an engine coupling as a maintenance component, and uses the shaft sleeve connector as an obstacle. The method of Chapter 2 is used to automate evaluate the visibility of the maintenance operation of a virtual person holding a wrench removal bolt. The DELMIA virtual simulation platform was used to verify the accessibility evaluation results, thus verifying the feasibility of this method.

3.1 *Preparatory preparation*

The virtual reality simulation platform chosen in this paper is DELMIA software, which is mainly used for mechanical motion simulation and ergonomics simulation in the aerospace field. Using Automation technology, secondary development of DELMIA can be performed in the Visual Basic 6.0 development environment. The virtual maintenance scene consists of a virtual prototype CAD model, a virtual human model, and a maintenance tool model[9]. Virtual maintenance scene is shown in Fig 4.

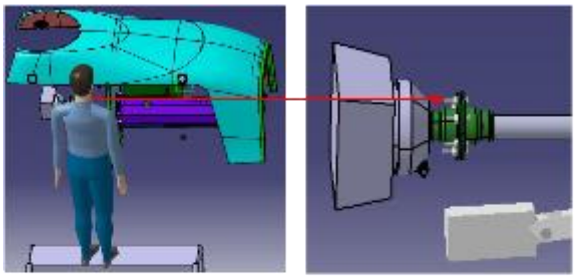


Figure 4. Virtual maintenance scene

Use the DELMIA interface function to collect CAD model data including maintenance parts and environmental part model data around the repair path, as well as to maintain tool size and attitude data. The input program extracts repair part feature point data and environmental part feature point data as well as virtual person related data.

3.2 *Visibility automated evaluation method*

In the evaluation of visibility, a virtual person root node spatial position coordinates (-585.478, -563.501, -167.99), the avatar's binocular center coordinate data (-567.683, -455.954, 443.943), Virtual person's head back and forth angle 9.952°, the maintenance part feature point data FA the feature point set FB of the shielding part have been obtained.

3.2.1 *Visual cone-based sight accessibility model verification*

Using the calculation method mentioned above, the DELMIA software is used to obtain the coordinates(x_i, y_i, z_i) of the feature point of the maintenance component in the visible cone coordinate system O by using the second change matrix, and then the repair is determined by using the visual cone accessibility evaluation model based on the visual cone. The distribution of component feature points in the field of maintenance personnel.

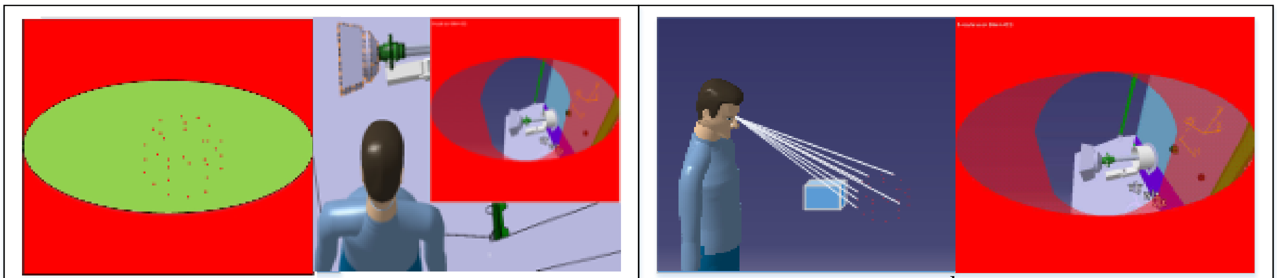
Using the MATLAB software for simulation calculations, each feature point coordinate is assigned to the parametric equation of the maximum field of view of the maintenance personnel. The calculation is available: For all the feature points, Equation(9) is established and the calculation result is shown in Figure 5 . From this,

$$(x_i/0.7002)^2 + (y_i/0.5774)^2 < z_i^2 \quad (9)$$

it can be obtained that the maintenance part has a good sight line accessibility design. Verifying in DELMIA software, as shown in Fig. 5(a), the maintenance part is located within the visual field of the virtual person under the current repair station, which verifies the accuracy of the method.

3.2.2 *Visual occlusion barrier evaluation model based on feature points verification*

Firstly, the visual parameter equation is constructed based on the data of the virtual human binocular center coordinates and the maintenance component feature point data. Secondly, the AABB axial bounding box for visually obstructing the obstacle is constructed based on the mask feature point data, and the eight surfaces of the bounding box are detected for interference. After calculation, as shown in Fig.5(b), no line of sight of the all feature points of the maintenance component interferes with the bounding box. It can be obtained that the maintenance part is not affected by the visual obstruction at the current viewing angle, and the visual accessibility of the maintenance part is well designed. Verifying in DELMIA software, as shown in Fig. 6, the line of sight of the maintenance component is not blocked by the surrounding environment components at the current viewing angle, which verifies the accuracy of the method in this paper.



a b

Figure 5.(a) Feature points in maintenance vision distribution and Delmia verification diagram (b)Visual occlusion evaluation effect and Delmia verification diagram

4. Conclusion

Visibility is a feature that allows the maintenance site to be easily and quickly reached by the design. In order to achieve objective, stereotyped and rapid accessibility analysis and evaluation, this paper constructs a visual cone-based visual line accessibility evaluation model and a visual line interference detection-based visual accessibility assessment model for both visual line reach and visual occlusion. Based on the previous two, a visual automation analysis and evaluation method based on virtual maintenance was proposed. Finally, the feasibility of the method is verified by concrete examples. The disadvantage of this paper is that the AABB axial bounding box is used as the extraction method. This method is simple in structure, simple in collision detection, and requires further research.

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