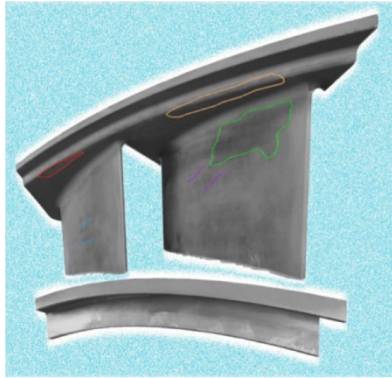


Simple 3D Inspection Recording System Using Photographic Projection to Create 3D Digital Records



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The method of recording damage information on a two-dimensional (2D) exploded view, in general, has the advantage of allowing an inspection record to be easily prepared. On the other hand, it has issues in terms of the fidelity of damage positions recorded on the exploded view and the precision of ex-post analyses of damaged regions. As such, technology for saving inspection records as three-dimensional (3D) digital information is sought after. Mitsubishi Heavy Industries, Ltd. (MHI) has developed technology for obtaining and recording the areas and photograph textures of damaged regions by reproducing the position/orientation of the photo (camera) of an object to be inspected on a 3D CG (Computer Graphics) space and projecting the damaged regions indicated on the photo and the photo on the target 3D CAD (Computer Aided Design) model. This technology allows preparation of a 3D digital inspection record with the same workload and equipment as those required for preparation of a 2D inspection record, thereby improving quality control.

1. Introduction

In MHI, we prepare the inspection records of the components (such as power generation turbines) which are used in high-temperature and high-pressure environments by rendering the information of damage such as erosion and cracks on 2D exploded views. However, the method of recording damage information on 2D exploded views generally has issues with the fidelity of damage positions on the exploded views and the precision of ex-post analyses of damaged regions and traceability of damage. Therefore, technology for saving inspection records as 3D digital information has been needed. There have also been requests from the inspection site about new technology that the working time should be approximately the same as that with the conventional method of recording damage information on a 2D exploded view and no expensive and dedicated devices such as 3D smart cameras and handy 3D scanners should be used in view of versatility on the assumption that it will be used in various environments and by users in Japan and overseas, in the open air, etc..

Against the background and issues described above, another company developed a technology for calculating pseudo-3D information (areas and lengths of damaged regions) with the use of a pseudo-image linked to the 3D CAD information corresponding to actual 2D image pixels. But the technology has a problem of lack of flexibility because the photographing position and angle of view need to completely match with those of the pseudo-image. Many other companies obtain 3D information by using large-scale devices and techniques (such as 3D smart cameras, handy 3D scanners and photogrammetry technique), but these methods lack versatility and require cost and time.

The purpose of this report is to develop a versatile 3D inspection recording system/technology for a wide range of products, which allows the areas and photograph textures of

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damaged regions to be obtained and recorded without depending on the photographing position and angle of view and without using any large-scale devices that require cost and time.

2. Characteristics of the developed technology

In order to meet the requests regarding inspection records, MHI has developed a technology/system for calculating the area of a damaged region from only the photo and further preparing a 3D digital inspection record from the obtained photo texture without depending on the photographing position/angle of view. **Table 1** shows the overview of the functions and uses of the developed technology/system.

Table 1 Overview of the functions and uses of the developed technology/system

No.	Developed function	Use	Technology or information used
1	Estimation of the position/orientation of the photo (camera)	<ul style="list-style-type: none"> Setting the position/orientation of the camera in a 3D CG space Checking for deformation on the subject 	<ul style="list-style-type: none"> 3D superimposition
2	Drawing of damaged regions (handwriting or automatic)	<ul style="list-style-type: none"> Indicating damaged regions on the inspection record 	<ul style="list-style-type: none"> GUI (Graphical User Interface), CNN (Convolutional Neural Network)
3	Projection of the photo and the damaged regions	<ul style="list-style-type: none"> Preparing a 3D inspection record 	<ul style="list-style-type: none"> 3D CG, geometric transformation RPA (Robotic Process Automation)
4	Calculation of the areas and lengths of damaged regions only from the photo	<ul style="list-style-type: none"> Recording and assessing the state of the damage 	<ul style="list-style-type: none"> Geometry/scale of 3D CAD model
5	Browsing of the 3D inspection records by a web browser	<ul style="list-style-type: none"> Sharing the information on inspection records 	<ul style="list-style-type: none"> glTF (GL Transmission Format)

3. Software and equipment configuration

The developed system/technology is configured to link the application (named as Simple 3D Inspection Recording System) developed by MHI and commercial 3D CG software. Free Blender Ver. 3.3.0⁽¹⁾ is used as 3D CG software and free libraries are used in processing of each program developed by MHI. The user may add camera equipment that can be used in the application and there is no limit to the kind of camera. Thus, compared to the software/devices requiring license fees, the developed system/technology requires lower initial costs and maintenance costs.

4. Operating procedure and processing process of the application

4.1 Overview of the operating procedure and the processing process

Table 2 shows the overview of the user's operating procedure and the processing process of this system. In the Simple 3D Inspection Recording System, a 3D digital inspection record is prepared according to the operating procedure and the processing process shown in Table 2. The details of each procedure and processing process are described in the following sections.

Table 2 Operating procedure and processing process

No.	Operating procedure and processing process	Manual operation	Automatic processing
(1)	Loading of a photo taken at an arbitrary camera position into the system	✓	
(2)	Indication of feature points and drawing of damaged regions	✓	✓
(3)	Automatic estimation of the position/orientation of the photo (camera) by use of the feature points		✓
(4)	Setting of the position/orientation of the camera in the 3D CG software		✓
(5)	Rendering based on the position/orientation of the camera in the 3D CG software		✓
(6)	Display of the rendered image on the Simple 3D Inspection Recording System (Confirmation of the estimated position/orientation of the camera)		✓
(7)	Projection of the photo and the damaged regions to the 3D CAD model in the 3D CG software		✓
(8)	Calculation of the areas/lengths of the damaged regions and display them on the Simple 3D Inspection Recording System		✓

4.2 Indication of feature points and drawing of damaged regions

The indication of feature points and the drawing of damaged regions on the photo loaded into this system in (1) and (2) of Table 2 are described below. **Figure 1** shows the indication of feature points and the drawing of damaged regions. The photo loaded into the Simple 3D Inspection Recording System in Figure 1 is of a turbine blade which is a component of a gas turbine.

The yellow cross marks on the screen are the feature points indicated by the user and several feature points are indicated on the screen of the Simple 3D Inspection Recording System for estimation of the camera position/orientation. Furthermore, it is desirable that these feature points are set in the position where the user can specify accurately on the photograph, such as the shape and pattern of the object to be inspected. The positions of the indicated feature points correspond to the positions on the 3D CAD model in the 3D CG spatial coordinate system. Feature points may be automatically identified by the machine learning function, instead of being indicated by the user.

On a turbine blade used in a high-temperature and high-pressure environment, various forms of damage (such as wear, erosion and cracks) occur, and the regions and forms of such damage are saved as inspection records. Damage can be drawn with color-coded frames (regions) and lines, and the forms of damage can be set for each product. For a turbine blade, frames are used to indicate wear and erosion and solid lines are used to indicate cracks. However, the regions and forms of damage indicated in this report are not of actual damage but of hypothetical damage for explanation purposes. After specifying the type of damage, the user indicates the damage by drawing the damaged region on the screen. For damage that can be identified on photographs, it is possible to automatically identify the kind and region of damage using machine learning functions, instead of being drawn by the user. It is also possible to incorporate functions that utilize conventional inspection recording and systems, such as automatically drawing damaged regions, by reading conventional inspection recording data into a simplified 3D inspection recording system.

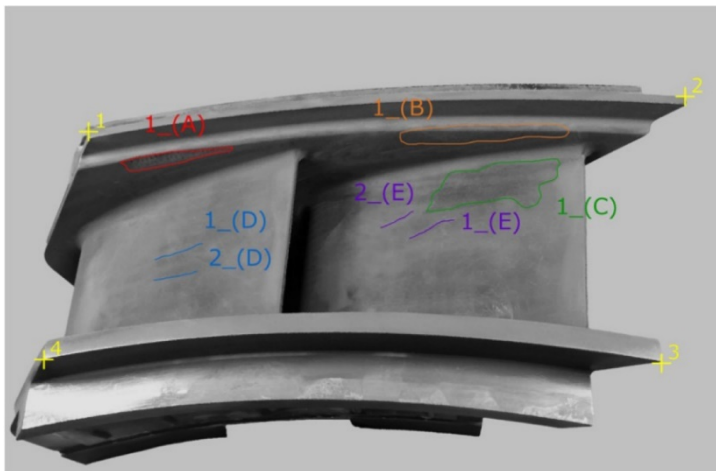


Figure 1 Indication of feature points and drawing of damaged regions

4.3 Estimation of the position/orientation of the camera

The estimation and setting of the position/orientation of the camera in the 3D CG in (3) and (4) of Table 2 are described below. **Figure 2** shows the initial position of the camera in the 3D CG software. In this 3D CG software, a 3D CAD model of the turbine blade corresponding to the photo of Figure 1 is placed. The orange-colored quadrangular pyramid represents a camera in the 3D CG software and the subject photographed by this camera is shown in the white frame. The Simple 3D Inspection Recording System reproduces the position/orientation of the photo arbitrarily taken by the user (of the camera used) to the camera in the 3D CG software regardless of the initial position of the camera in the 3D CG software. As described in section 4.2, the user only indicates several feature points to estimate the position/orientation of the camera by which the user arbitrarily took the photo without using any fixing apparatus such as jigs. Thus, the system requires no complicated setting, is easy to use and can be applied to a broad range of photos (positions, orientations and angles of view of the camera).

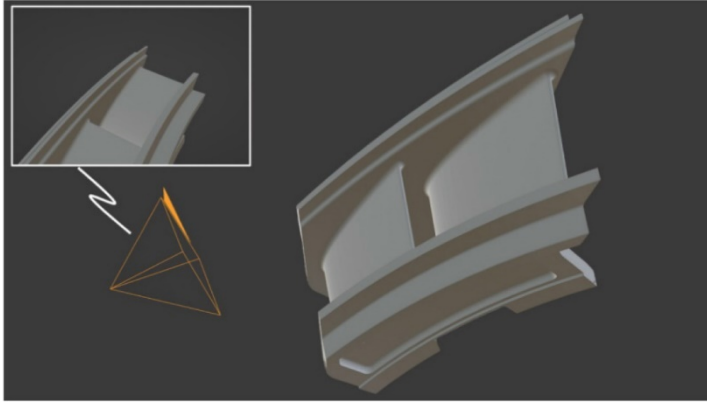


Figure 2 Initial position of the camera in the 3D CG software

4.4 Confirmation of the estimated position/orientation of the camera

The confirmation of the estimated position/orientation of the camera in (5) and (6) of Table 2 is described below. In the developed Simple 3D Inspection Recording System, it can be confirmed on the screen that the position/orientation of the camera in the 3D CG software has been automatically adjusted. In **Figure 3**, the image rendered by automatic processing is superimposed and displayed on the photo. Rendering is the process of converting objects in 3D space into 2D images in 3D CG production. In Figure 3, the rendered image is displayed with the transparency of 60% (semi-transparency), and it should be noted that the position/orientation of the 3D CAD model in the 3D CG software is completely in agreement with that of the subject of the photo. By superimposing the image on the photo like this, we can not only confirm that the position/orientation of the camera in the 3D CG software has been adjusted but also check whether there is any deformation on the subject.

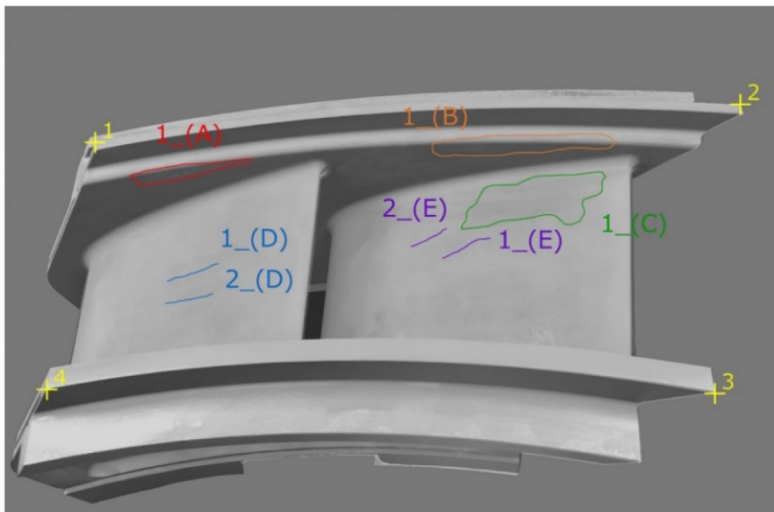


Figure 3 State of the image rendered by automatic processing being superimposed and displayed on the photo

4.5 Projection of the photo and the damaged regions

The projection of the photo and the damaged regions in (7) of Table 2 is described below. After the position/orientation of the camera in the 3D CG software is adjusted, the photo and the damaged regions are automatically projected to the 3D CAD model in the 3D CG software. The damaged regions were drawn on the screen by the user or automatically identified by use of the machine learning function. **Figure 4** shows the photo and damaged regions projected to the 3D CAD model by automatic processing. The photo and damaged regions are projected according to the geometry of the 3D CAD model and saved as a 3D inspection record (Blender file format). The above-described CG processing is automatically executed by program control. Also, multiple photos taken from different positions/directions can be projected to the same 3D CAD model.

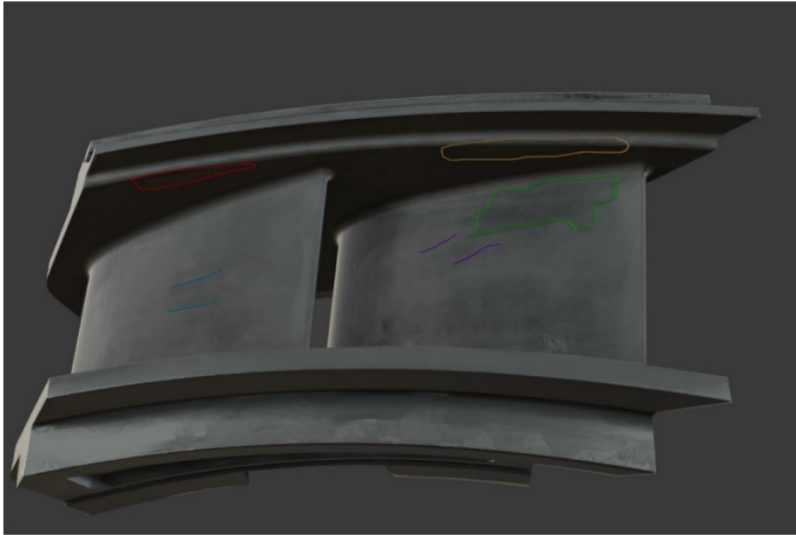


Figure 4 Photo and damaged regions projected to the 3D CAD model by automatic processing

4.6 Calculation of the areas/lengths of the damaged regions

The calculation and display of the areas/lengths of the damaged regions in (8) of Table 2 are described below. The areas (mm^2) or lengths (mm) of the damaged regions projected to the 3D CAD model are calculated based on the geometry and scale of the 3D CAD model by automatic processing. The calculated areas/lengths are displayed on the Simple 3D Inspection Recording System and saved as digital information. In **Figure 5**, the areas and lengths of the damaged regions are displayed on the Simple 3D Inspection Recording System. The areas or lengths of the damaged regions are displayed near the regions drawn on the screen by the user or near the regions automatically identified by use of the machine learning function in the black outlined rectangles. In this report, however, each dimension value, which is product information, is hidden. The above processing allows the areas or length of damaged regions to be calculated only with the photo and eliminates the need for measuring damaged regions on an actual product.

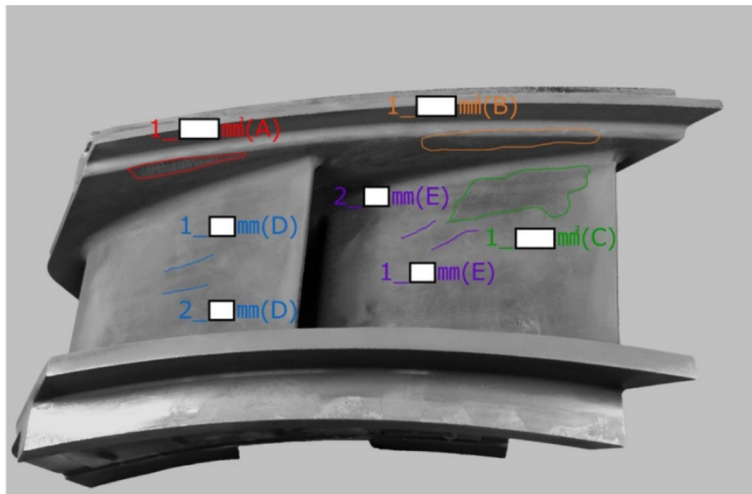


Figure 5 Display of the areas/lengths of the damaged regions

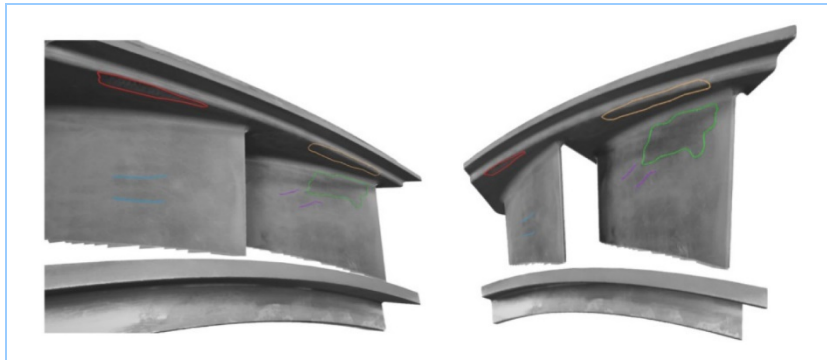
5. 3D digital inspection record

The information obtained by the operation and processing in chapter 4 is used to prepare a 3D digital inspection record. **Table 3** shows the file formats that can be used for a 3D digital inspection record in which the photo and the damaged regions are projected to a 3D CAD model. Either one of the two typical file formats which store photo texture information is selected to prepare a 3D digital inspection record.

Table 3 Output file formats for 3D digital inspection record

File format	Description of file format	Texture information
.blender	Dedicated file format for Blender	Texture information is contained inside.
.obj .mtl	obj is a 3D model format developed by Wavefront Technologies. mtl is file which contains the color and texture information of models.	Image files are required for display of texture.
.glb (glTF 2.0)	File format for 3D models running on a web browser	Texture information is contained inside.

Figure 6 shows an example of one of the projected turbine blade photos displayed as a 3D digital inspection record. In Figure 6, the 3D digital inspection record in glb format is displayed by use of the 3D Viewer installed on the Microsoft Windows OS. The right and left views show the 3D digital inspection record displayed in different orientations (viewpoints). This 3D digital inspection record is designed to display the photo (texture) only on the surface of the 3D CAD model having the regions to be projected and the surfaces where no photo is projected are blank. The frames and lines for the damaged regions indicated on the Simple 3D Inspection Recording System can be checked on the 3D digital inspection record. Thus, compared to the method of recording the damage information to 2D exploded views, 3D digital inspection records allow improvement of quality control in terms of the accuracy of the information of damage positions and regions.

**Figure 6 3D digital inspection record using the projected photo**

6. Conclusion

With this technology/system, the position/orientation of the photo arbitrarily taken by camera equipment (the position/orientation of the camera) is reproduced on a 3D CG space and the damaged regions indicated on the photo and the photo are projected on the target 3D CAD model. By this, it became possible to obtain the texture information and automatically calculate the areas or lengths of the damaged regions based on the geometry of the 3D CAD model. One of the features of this technology/system is that it can prepare a 3D digital inspection record easily and inexpensively by using a general photographing device (camera), not requiring a less versatile and expensive device, and in about the same working time as the conventional method for recording damage information on a 2D exploded view. Furthermore, since damaged regions are drawn on the photo displayed on the system screen, the recording accuracy and reproducibility for damage positions and regions can be improved. In addition, use of 3D digital inspection records is effective in improving the precision of ex-post analysis of damaged regions and traceability of damage. Moving forward, we will develop functions required for each inspection record or assessment method to which this system is applied, thereby extending the range of application.

References

- (1) Blender official website, (2022), <https://www.blender.org/>