Three-Dimensional Measurement System for In-Vessel Visual Inspection
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ABSTRACT

The main roles of in-vessel visual inspection (IVVI) are to observe internal structures and crack on the structure surface. For accurately checking those matters by visual inspection, inspectors sometimes need three-dimensional (3D) recognitions. Therefore, we developed a prototype system that has only one inspection head to obtain 3D measurements. This system is based on our 3D Visual Testing (3DVT) technique that we have been developing. This report proposes that prototype measurement head and performance of this prototype evaluates by flat test piece and test piece which is simulated internal structure.

INTRODUCTION

As techniques to inspect nuclear reactor internal structures, visual testing (VT), ultrasonic testing (UT) and eddy-current testing (ECT) are usually used. In particular, the VT with remote CCD cameras or pickup tube cameras is most widely applied to observe the surface condition of the structures, because its configuration is easier than the others. However, in traditional VT, there is issue that is hard to judge undulation of inspection surface, because of confirming camera images without 3D information on monitor. Therefore, when it is maintained and repaired internal structures especially, inspectors need several three-dimensional (3D) measurements: the 3D structure shape, the distance between structural objects and the 3D path of cracks on surface.

There are some measurement methods of 3D structure shape (surface); stereo method by 2 cameras, light-section method and displacement method by laser, and so on. Method by laser is generally characterized by high-precision measurement. And we have been developing 3D shape measurement technique which is based on stereo method. This technique is characterized that it is able to measure 3D shape in an area in short time.

Therefore, in this paper, we developed a prototype that has only one inspection head to obtain above 3D measurement, and considered performance evaluation of 3DVT (3D Visual Testing) technique for shape measurement. And we attempted to introduce simulated actual shape of internal structure.

SUMMARY OF 3DVT TECHNIQUE

The 3DVT technique is measuring method which is applied on image processing by using stereo image with 2 cameras. Fig. 1 shows basic concept and camera control. Because of responding to measure in different work distance (covering from crack length and etc. (micro use) to distance between structure, level of structure and etc. (macro use)), it is necessary to cross optical axes of 2 cameras on measurement object.

This 3DVT technique is configured to rotate camera2 in Fig. 1 relative to camera1. And it is automatically controlled a camera in the most suitable angle of rotation depending on work distance by image processing. More specifically, firstly, gap of image center of 2 cameras is processed by image processing on target point in measurement object. Rotating angle of camera2 in Fig. 1 is controlled by matching image center of 2 cameras. Consequently, the 3DVT technique is achieved to be able to use variable distance between camera and inspection object; micro measurement is performed short distance.

And it is described process of measurement for 3DVT technique as follows. In first, the relative positions and rotating angles of 2 cameras (camera parameters) are calibrated using chessboard and etc. Cross points of black and white on chessboard are obtained each image of 2
cameras automatically. And as each distance of cross points on chessboard is given, we can calibrate each camera using image pixels of these cross points. Here, origin point of coordinate system is camera position of Camera 1 in Fig. 1.

Next, because of obtaining 3D-coordinates, images taken by 2 cameras are processed that same image pixels are obtained to correspond to same positions on measurement object. Finally, the 3D-coordinates are calculated by co-linearity condition using each corresponding image pixels and calibrated camera parameters.

These obtained 3D-coordinates provide crack length on 3D path, distance of structures, 3D shape model (wire-frame, surface and texture model) and cross-section view on measured surface of object and so on.

And, we developed prototype 3DVT head for Jet-pump that concept of this head is measurement for micro and macro use in Fig. 2. Measurement resolution and work distance of micro use is each 0.5mm, 100mm and measurement resolution and work distance of macro use is each 5.0mm, 600mm. We attempted to introduce Jet-pump on mockup experiment by prototype 3DVT head and confirmed to able to measure the surface of Jet-pump.

Figure 1 - Configuration of 3DVT technique

Figure 2 – Prototype of 3DVT head for Jet-pump
DEVELOPMENT OF PROTOTYPE MEASUREMENT HEAD

As described above, our 3DVT technique has function of changeable work distance between camera and measurement object by rotating a camera. In this report, we developed prototype measurement head, because of measuring one of internal structures; for example welded surface and so on. Here, we are going to attempt to measure test piece which is simulated internal structure. In this experiment, this prototype measurement head don’t need rotating camera, since work distance is fixed.

Fig. 3 shows a measurement system configuration with prototype measurement head. This prototype measurement head consists of 2 underwater cameras and underwater light, each camera is connected camera control unit and underwater light is also connected light control unit. Moreover, image frames of 2 cameras which are recorded by manual of operator are inputted to PC. The size of prototype measurement head is 50mm (L)*70mm (W)*30mm (H). This head is mounted on access device which shows Fig. 4.

PERFORMANCE EVALUATION OF MEASUREMENT SYSTEM

In order to confirm measurement performance, prototype measurement system is performed an evaluation test that is measured flat test piece as shown in Fig. 5.

In this experiment, position of prototype measurement head of this head was moved by access device at standard measurement position (Position A), and Position B and Position C are measured surface shape of a flat test piece relative to the Position A to move each 0.5mm and 1.0mm. Table 1
shows results that are measured surface shape of a flat test piece of each measurement position. And Table 1 showed two trials of measurement results that were measured at each position and showed the mean and standard deviation of the measured surface shape. Differences between mean of Position A’s result and each mean of Position B and C are also shown in Table 1.

As results, Position B and C moved 0.5mm and 1.0mm by access device from Position A, and the difference of the measurement result of Position A was 0.5mm (the first trial) and 0.4mm (the second trial) in the case of Position B, was also 1.0mm (the first trial) and 0.9mm (the second trial) in the case of Position C. In addition, the standard deviations of measurement results were confirmed that they were 0.3mm at the maximum.

Consequently, this developed measurement system was confirmed that measurement performance of this measurement head was less than measurement resolution. Measurement resolution of this measurement head was designed in 0.5mm. And, we confirmed to able to measure difference in level of 0.5mm.

<table>
<thead>
<tr>
<th>Measurement Position (distance from Position A)</th>
<th>1st trial</th>
<th>2nd trial</th>
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<tbody>
<tr>
<td></td>
<td>Mean (distance from Position A)</td>
<td>Standard deviation</td>
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<tr>
<td>Position A (0.0mm)</td>
<td>152.1mm (0.0mm)</td>
<td>0.2mm</td>
</tr>
<tr>
<td>Position B (0.5mm)</td>
<td>152.6mm (0.5mm)</td>
<td>0.2mm</td>
</tr>
<tr>
<td>Position C (1.0mm)</td>
<td>153.1mm (1.0mm)</td>
<td>0.2mm</td>
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</table>

Table 1 - Measurement result

**MOCKUP EXPERIMENT**

We conducted mockup experiments for demonstrating the effectiveness of 3DVT technique and the applicability of prototype measurement head using test piece of actual equipment shape which is simulated Control Rod Device (CRD) stub tube. We evaluated the possibility of measurement at J welding part that is welded CRD Housing and CRD stub tube, and at 3D welding part that is welded CRD stub tube and Nuclear Reactor Pressure Vessel (RPV) in Fig. 6. And as measuring above corresponding area, we conducted by the method how was similar to actual measurement.

Fig. 7 shows the measurement results. As shown in Fig. 7, these results show that each welding part of J welding part and 3D welding part were able to measure surface shape of welding part, and our 3DVT technique and prototype measurement head are effective. Although impossible areas of measurement existed in welding part, these areas occur by surface condition that is weakness of the 3DVT technique. This reason is surface condition of simulated test piece. In addition, since surface was painted only black color, there is a reason why surface of simulated test piece had no pattern. However, as a result of checking internal images and actual surface is adhered crud and so on
in past experiments, we consider that actual equipment is easier to measure this test piece for actual surface conditions.

CONCLUSIONS

We developed the prototype measurement system by the 3DVT technique, and conducted experiment for demonstrating the effectiveness of 3DVT technique and mockup experiment using simulated test piece of actual equipment shape by prototype measurement head of this system.

As results, in first, performance evaluation of prototype measurement head is confirmed that standard deviation of measurement result was less than measurement resolution in design. And, we achieved that each welding part of J welding part (CRD Housing and CRD stub tube) and 3D welding part (CRD stub tube and Nuclear Reactor Pressure Vessel) were able to measure surface shape of welding part. And the part that was impossible of measurement occurred in, since the surface of this test piece was condition which is weak for the 3DVT technique. However, as a feasibility result of checking internal images and the surface of interval equipments was adhered crud from past
experiment, we consider that the prototype measurement head is able to measure the actual equipment, because it was no sense at all that actual surface condition is same condition of this test piece’s surface.