Nuclear Fuel Rod Displacement Measurement using a Wide-Area CCD Sensor

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1. Introduction

In this paper, a displacement measurement technology is described for nuclear fuel rod using COTS (commercial–off-the-shelf) wide area CCD sensor. The displacement measurement system include Nikon D80 digital camera having a wide area CCD sensor (size: 23.6×15.8mm, pixels: 3872×2592), telescopic zoom lens(75~300mm) to capture the image at the distance as far as possible, semiconductor laser marker, and optical accessories. The basic idea of the displacement measurement is to illuminate the outer surface of the fuel rod with collimated laser spot beam at an angle of 45 degrees. The relative motion of fuel rod in the horizontal direction causes the illuminated laser spot beam to move vertically along the surface of the fuel rod as much as the same displacement in the horizontal direction. The resulting change of laser spot position in the surface of the fuel rod is imaged by means of a high definition wide-area CCD camera. The comparison and subtraction of the two images, taken before and after the micro movement of the fuel rod, reveals the measures of the displacement of the fuel rod. In this paper we shows result for the displacement measurements of the nuclear fuel rod using both the high definition wide-area CCD sensor and image processing technology.

2. Experiment

A block diagram of a typical displacement measurement set up for the fuel rod is shown in Fig. 1.

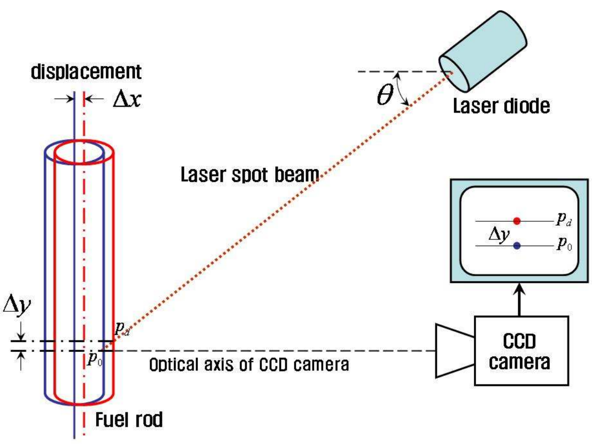

Fig. 1. A schematic diagram for the displacement measurement of nuclear fuel rod.

As shown in Fig. 1, if the fuel rod moved to the horizontal direction $(p_0 \rightarrow p_d)$, the illuminated laser spot beam in the surface of the rod is projected vertically to the image plane of the CCD camera. Assumed that the incident beam angle of laser diode is 45 degrees, the displacement (Δx) of the fuel rod in the x-axis direction is mapped to the same one (Δy) along the vertical axis[1].

$$\tan\theta = \frac{\Delta y}{\Delta x} \qquad (1)$$

$$\Delta x = \Delta y\,, \quad \theta = \pi/4 \qquad (2)$$

Therefore, using both the high definition wide-area CCD sensor (Nikon D80 digital camera) and image processing algorithm, we could measure the displacement of fuel rod accurately.

In the case of conventional CCD camera system (sensor size: 1/4" and 32× zoom lens), the pixel resolution at the 2m distance is about 0.151mm/pixel. But if the high definition wide-area CCD sensor (size: 23.6×15.8mm and telescopic 300mm lens) were used at the same 2m distance, the pixel resolution is about 44um/pixel. The two comparative images using conventional CCD sensor and wide-area sensor are shown Fig. 2.

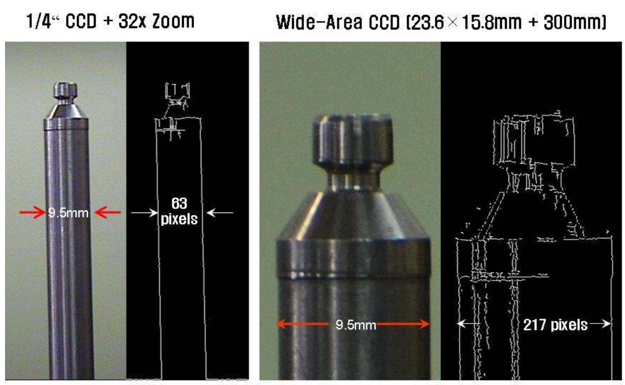

Fig. 2. Comparative images of the two CCD sensor systems

Using background subtraction technique as the image processing algorithm, we extracted illuminated laser spot beam area. At first reference image is captured prior to the illumination of the laser spot beam. Second illuminated laser spot image of the surface of fuel is captured. Subtraction reference image (without laser spot beam) from the second image (with laser spot beam) reveals laser spot beam pattern in the subtracted image plane. Fig. 3 shows an image processing algorithm.

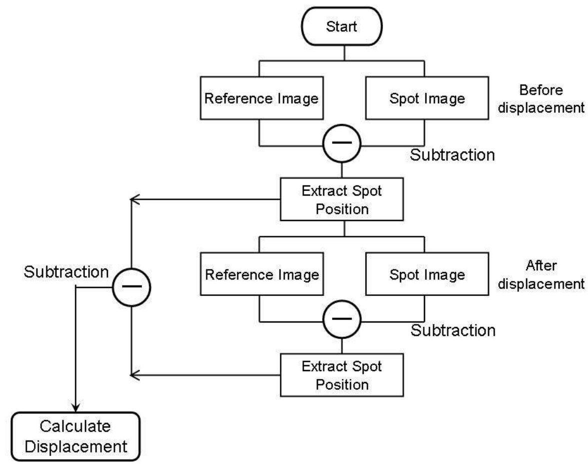

Fig. 3. Image processing flowchart for the displacement measurement

We extracted the spot position of the illuminated laser beam as the center position of the contour in the subtraction image as shown in Fig. 4.

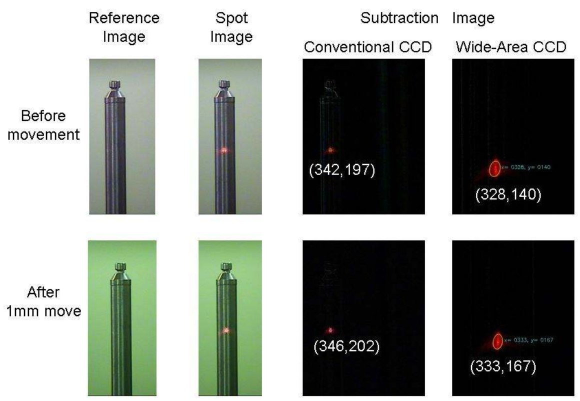

Fig. 4. The image sequences for the displacement measurement of the fuel rod.

As shown in Fig. 4, the pixels difference in the vertical direction between the reference image (without movement) and the displacement image depicts the actual displacement of the fuel rod in the horizontal direction. As the magnitude of pixels difference of the wide-area CCD sensor is greater than one of the conventional CCD sensor, the measurement resolution for the displacement of the fuel rod using the wide-area CCD sensor is higher accuracy than that using the conventional CCD. Table 1 summarizes the experimental result.

Table 1. Experimental results of displacement measurement for the two CCD sensor systems.

CCD Sensor	Conventional CCD (1/4“ CCD + 32× Zoom Lens)	Wide-Area CCD (23.6×15.8mm + 300mm lens)
Pixel differences	5 pixels	27 pixels
Resolution	0.2mm/pixel	37um/pixel

Acknowledgements

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3. Conclusions

In this paper, a displacement measurement technology is described for nuclear fuel rod using COTS (commercial–off-the-shelf) wide area CCD sensor. The basic idea of the displacement measurement is to illuminate the outer surface of the fuel rod with collimated laser spot beam at an angle of 45 degrees. The relative motion of fuel rod in the horizontal direction causes the illuminated laser spot beam to move vertically along the surface of the fuel rod as much as the same displacement in the horizontal direction. The comparison and subtraction of the two images, taken before and after the micro movement of the fuel rod, reveals the measures of the displacement of the fuel rod. Using the COTS digital camera, which have wide-area CCD sensor, and applying the image processing algorithm, the superior measurement resolution for the displacement of the fuel rod was obtained.

REFERENCES

[1] Japan Patent, “Nuclear Fuel Assembly Inspection Unit”, Mitsubishi Nuclear Fuel Company, JP 1998-274690