Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

A Non-contact Shape Measuring System Using an Artificial Neural Network

Woo-tae Jeong, Myung-chan Lee, and Duck-joon Koh
Korea Atomic Energy Research Institute

Hyung-suck Cho
Korea Advanced Instutute of Science and Technology

Abstract

We developed a non-contact shape measuring device using computer image processing technology. We present a method of calibrating a CCD video camera and a laser range finder which is the most important step toward making an accurate shape measuring system. An artificial neural network is used for the calibration. Our measurement system is composed of a semiconductor laser, a CCD video camera, a personal computer, and a linear motion table. We think that the developed system could be used for measuring the change in shape of the spent nuclear fuel rod before and after irradiation which is one of the most important tasks for developing a better nuclear fuel. A radiation shield is suggested for the possible utilization of the range finder in radioactive environment.

1. Introduction

Non-contact shape measurement or range finding has been one of the most active research areas in computer vision and robotics. There are two methods in non-contact shape measurement. One is a flight time measuring method which calculates distance from the flight time of the waves such as a pulsed laser beam or an ultrasound, and the other is a triangulation method which calculates distance from the triangle made by two cameras (or a camera and a active light source) and a target object. Making an accurate range finder using a pulsed laser beam is possible, but a very accurate optical device and a scanning mechanism are necessary that the price is generally much higher than the other systems using the triangulation method. An ultrasound is sometimes used to recognize obstacles for the navigation of a industrial robot, but the resolution of the measured distance is relatively poor. Triangulation method using a structured light beam is cheaper and the accuracy is not so bad compared to the flight time method that it could be a better option for a restricted indoor environment. Many papers on the triangulation method have been published[1,2,3] but there not many papers on the hot application of the laser range finder in nuclear field. We designed a laser range finder for possible application to the examination of irradiated nuclear fuels.

2. Laser Range Finder

The laser range finder we developed is composed of a semiconductor laser, a cylindrical lens, a CCD camera, and a linear motion table as shown in Fig. 1. A collimated laser beam is converted into a slit beam by using a cylindrical lens which is attached in front of the laser. The projected laser slit beam makes a stripe when it encounters a target object of which the shape and the dimension are our major concern. The shape of the projected stripe is dependent upon the shape and the dimension of the target object and the reletive position and orientation of the laser and the CCD camera. The image captured by the CCD camera may includes not only the projected stripe but unnecessary noises. The optical band-pass filter which is attached in front of the CCD camera removes the unnecessary noises. The image captured using the optical band-pass filter contains only the projected slit beam. It makes the image processing easier.

We can only know the shape and the dimension of the projected surface, so scanning is necessary if we want to get more information about the entire surface of the target object. We attached a linear motion table for the scanning of the entire target object. A ball screw is attached to a servo motor to translate the sensor head up and down. We control the position of the servo motor using the servo motor controller which is embedded in a slot of PC486.

We projected a laser slit beam onto the target object, and acquired an image using the CCD camera through an optical band-pass filter. Unfortunately, the stripe is not narrow enough to calculate the exact range. To get the coordinates of the laser stripe in subpixel accuracy, we applied weighted average method. As shown in Fig. 2, we found the row number of the brightest point in each column of the image. The 5 pixels in a row before and after the brightest row are selected for the calculation of weighted average. Let r denotes the row number, q^* the row number of the laser slit beam in sub-pixel accuracy calculated by the weighted average method, and $G(r)$ the gray level at row r, then we calculate q^* using the following equation.

$$q^* = \frac{\sum_{r=q-5}^{q+5} G(r) \cdot r}{\sum_{r=q-5}^{q+5} G(r)}$$

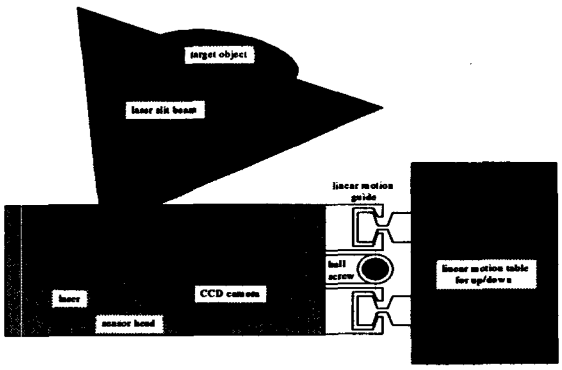

Fig. 1 A Schematic Diagram of the Laser Range Finder

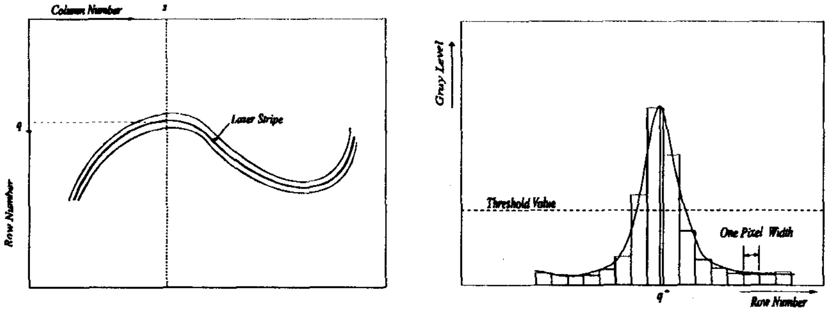

Fig. 2 A Schematic Diagram for Calculating the Row Number (q^*) of a Laser Stripe with Sub-pixel Accuracy

3. Calibration of a Camera and a Laser Range Finder

The calibration of a camera is a procedure to get parameters which relate 3-D world coordinates to camera image plane coordinates. Calibration parameters could be classfied by two different categories. The first category includes internal(intrinsic) camera parameters such as the effective focal length of the camera lens, the distortion coefficients of the lens, and the coordinates of the center of distortion. The second category includes external(extrinsic) camera parameters such as rotation angles and translation components for the transform between the world and camera coordinate frames.

There have been various researches on camera calibration since the first application of image processing technology to geometrical measurement. An early type of camera calibration was based on a pin hole camera model which is very simple. The parameters to be calibrated for a pin hole camera were 6 external parameters and 1 internal parameter. Other calibration parameters including distortion coefficients are ignored. Stimulated by the demands of higher precision, many calibration techniques have been developed. Tsai developed coplanar and noncoplanar calibration technique[3].

We tried to calibrated our laser range finder using artificial neural network. We made a calibration chart which have small circles as shown in Fig.3, and measured the coordinates of the small circles using a vernier caliper. Then, a frame of the image of the calibration chart is captured by using a CCD video camera and a frame grabber. The coordinates of the circles in the captured image were calculated by the image processing software which was written by us.

The procedures for calculating the center coordinates of each calibration point is as follows: 1) acquire several frames of the image of the calibration chart, and make an averaged image, 2) make binary image using an appropriate threshold, 3) reverse the image to make the marks to have higher gray value and the background has lower gray value, 4) label the reversed image, 5) calculate the center of each marks.

To reduce the noises which may be included during the image acquisition, several frames are acquired and averaged. Fig. 3 shows original calibration chart and Fig. 4 shows the labelled image of the calibration chart. Each cross mark on Fig. 4 indicates the center of each circle.

Our calibration method does not require the calculation of internal and external camera parameters. Instead, the look-up table for the corresponding points between the coordinates of the original calibration points in Fig. 3 and the labeled points in Fig. 4 is necessary. For example, we can measure the coordinates of each calibration point using a vernier caliper or a micrometer. The image of the calibration chart captured by using a frame grabber is processed and labeled as shown in Fig. 4. We used the coordinates of the original calibration chart as the input parameters, and the coordinates of each point of the labeled calibration chart as the output parametes of a multi-layer artificial neural network as shown in Fig. 5.

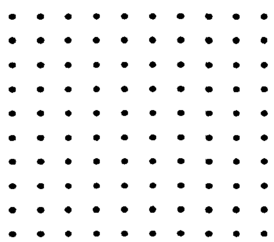

Fig. 3 Original Calibration Chart

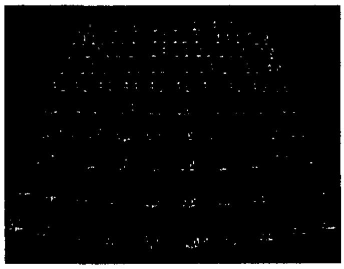

Fig. 4 Labeled Image of the Calibration Chart

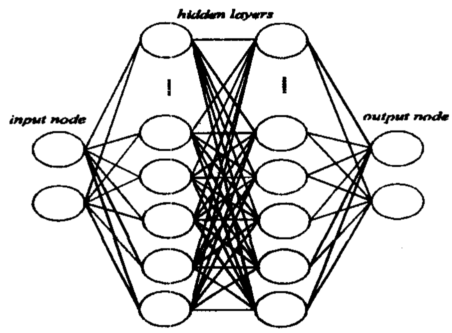

Fig. 5 Multi-layer Artificial Neural Network Used for the Calibration of the Laser Range Finder

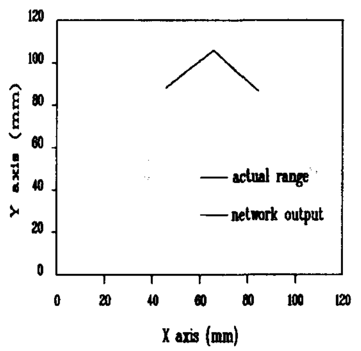

Fig. 6 Shape Measurement for a Triangular Bar
(2 Hidden Layers, 10 Nodes for Each Layer)

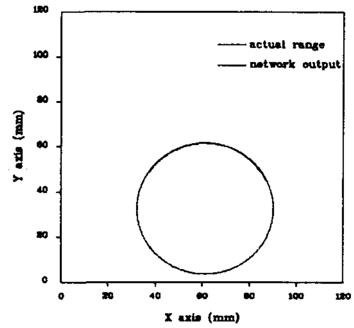

Fig. 7 Shape Measurement for a Cylindrical Object
(2 Hidden Layers, 10 Nodes for Each Layer)

Several experiments to measure the range of a triangular bar and a circular cylinder were done to test the validity of using a artificial neural network based calibration of a laser range finder. Actual range data are compared to the output of artificial neural network. Fig. 6 and 7 shows the range finding results for the triangular bar and the circular cylinder. As shown in the figures, the error of range finding was less than 0.2 mm which is reasonable for most computer vision applications. The accuracy was highly dependent on the architecture of the artificial neural network that careful selection of the neural network archtecture is necessary.

4. Radiation Protection

The range finding system We presented here is designed only for cold environment, but simple modification could make it applicable for hot environment. CCD image sensor is very sensitive to electromagnetic waves having short wavelength, so packing the radiation sensitive hardware in a radiation shield is necessary. The simple and efficient method to do this is designing the collimator similar to periscope in shape as shown in Fig. 8. The radiation such gamma ray or neutron beam go through the mirror, but the visible light is reflected on the surface of the mirror. Thus, only visible light can reach to the CCD image sensor, but completely preventing the incoming radiation to reach CCD is impossible because some radiation particles collide with the material of the collimator and scatter. Careful consideration of the effects of the incoming radiation through the radiation shield is possible by using Monte Carlo code such as MCNP(Monte Carlo Neutron and Photon Transport Code).

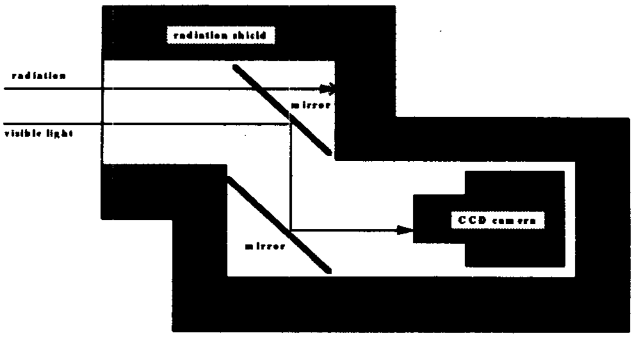

Fig. 8 Suggested Radiation Shield to Protect a CCD Camera

5. Conclusions

A laser range finder which could be used for measuring the shape and the dimension of a spent nuclear fuel rod was suggested. A method of calibrating the laser range finder using artificial neural network was established. The accuracy of 0.2 mm in range finding was obtained, but the accuracy was dependent on the architecture of the neural network. The method of calibrating a laser range finder using an artificial neural network makes the separate calibration of a camera and a laser slit beam unnecessary. Training neural network is all that we should do for the calibration of a laser range finder. Careful consideration is also necessary to avoid hazadous effects of a ionizing radiation. CCD image sensors are very vulnerable to those radiations emitted from fission. Thus we suggested an architecture for a radiation shield to protect the radiation sensitive hardware from the radiations. Further computer simulation using Monte Carlo code is necessary to decide the specific dimensions. Hot test was not made yet, thus it should be made before an actual application of the sensor in a hot environment.

References

[1] Guo-Qing Wei and Song De Ma, "Implicit and Explicit Camera Calibration: Theory and Experiments," *IEEE Trans. Pattern. Anal. and Mach. Intell.*, vol. 16, no. 5, pp. 469-480, May 1994.

[2] R. Y. Tsai and R. K. Lenz, "Real Time Versatile Robtics Hand/Eye Calibration using 3D Machine Vision," *in Proc. IEEE Conf. Robotics and Automation*, vol. 1, pp. 554-561, 1988.

[3] R. Y. Tsai, "A Versatile Camera Calibration Technique for High-Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses," *IEEE J. Robotics and Automation*, vol. RA-3, no. 4. pp. 323-344, 1987.