International Journal of Engineering & Technology, 7 (3.13) (2018) 51-54

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Method for Contactless Determination of the Height of A Fuel Assembly by Means of A 3-D Reconstruction of A Collinear Stereopair Images

S. Kravtsov, K. Rumyantsev*

Southern Federal University, Russia, Rostov on Don
**Corresponding author E-mail: rke2004@mail.ru*

Abstract

A method for determining the head height of fuel assemblies in the reactor core of a nuclear power unit using a 3-D reconstruction of a stereopair of collinear images is considered. The method is based on the principle of statistical evaluation of the height of a set of points for a 3-D reconstruction of the contour of the head of the fuel assembly. To obtain a stereopair of images, it is suggested to use a collinear digital stereo-vision system. A model experiment was carried out. The results are compared with the known method for determining the height of the heads of fuel assemblies, based on an estimate of the height of the centers of gravity of the contours of fuel assembly heads. The proposed method shows a higher accuracy in solving the problem of determining the heights of fuel assembly heads in comparison with the known method.

Keywords: *Digital stereo vision system, 3-D reconstruction, measurement accuracy.*

1. Introduction

1.1. The Urgency of the Problem of Non-Contact Determination of the Height of the Head of the Fuel Assembly

Safe operation of nuclear power facilities is inextricably linked with constant technological control of the core of the nuclear reactor. The actual issue is the operational technological control of the parameters of fuel assemblies in the reactor core of the power unit of the nuclear power plant. Such control is necessary to determine the difference in height of their position, to identify deformations that may arise during operation. At present, full-fledged technological control is carried out by a contact method using special equipment, periodically after the procedures for replacing fuel cells in a shut-down reactor. This procedure is very expensive and time consuming, and also time-consuming. It should be noted that the operational control of the parameters of fuel assemblies in the active zone of the reactor with its regular work is a very topical issue for the nuclear power industry today. Obviously, such control should be carried out in a non-contact way due to security measures.

The purpose of the research was to analyze the prospects for using digital collinear stereo vision systems for contactless monitoring of the heat parameters of the releasing assembly through a complete three-dimensional reconstruction of the fuel assembly head contours.

1.2. Existing Approaches for the Non-Contact Determination of the Height of the Head of the Fuel Assembly

Existing developments [1, 2] in the field of noncontact monitoring of the parameters of fuel assemblies in the core of the reactor are based on the use of standard means of video monitoring. The standard cameras are monochrome, have a very modest by modern standards, resolution. They are attached to a special rod that can move in the plane of the active zone at an angle to it, the rod can perform a controlled rotation along its axis by a given angle.

This makes it possible to obtain images of fuel assembly heads from different angles, and then to determine their heights. Analysis of the height difference is performed within the so-called cell, formed by a group of seven fuel assemblies (Fig. 1).

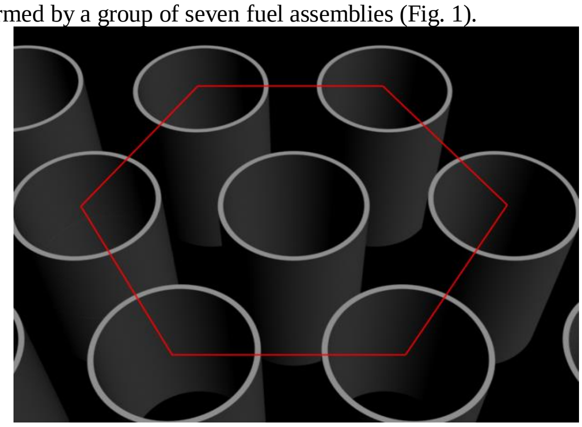

Fig.1: Cell model of the seven heads of fuel assemblies

Measurements of the height of the heads of fuel assemblies are carried out by successively performing the following operations [3]:

• locating the camera strictly at specified points in the space to obtain a series of images;

• estimation of image quality by histogram of brightness distribution;

• removal of minor details in images (through low-frequency filtering);
• highlighting the boundaries of the upper surfaces of the heat of the releasing assembly;
• approximation of the upper surface of the heat of the releasing assembly by an ellipse;
• determination of the coordinates of the centers of gravity of the upper surfaces of the heads of the heat of the releasing assembly in stereopair images;
• calculation of the coordinates of the centers of gravity of the upper surfaces of the heads of the heat generating assembly in three-dimensional reconstruction.

In the development of these methods, it is possible to single out the works [4] that allow to select those necessary views of observation that allow minimizing the system error in determining the height of the head of the heat emitting assembly entering the cell. Despite the fairly optimistic results achieved, we should be very skeptical of them. First, in order to minimize elevation error errors, it is necessary to fix the cell scene from six different angles. In this case, the minimum error in determining the height for a certain heat, the releasing assembly is achieved by considering only a certain stereopair of images from a possible set. This involves, first, the execution of the above iterations for six images. It is also necessary to have an accurate knowledge of pairs of positions that will give a better estimate of the height of a certain head, the heat emitting assembly in the cell. That is, the computational complexity of the solution of the problem multiplies. Secondly, it is difficult to imagine such a rotary device, which would allow fixing six different camera positions without errors in the rotation angles. Such an event is unlikely in practice. And thirdly, the conclusions drawn in [4] refer to the case when there is no difference in the height of the heads of the heat of the releasing assemblies.

Therefore, the task of operational contactless monitoring of the parameters of heat, the releasing assembly is considered to be an urgent task for the safe operation of nuclear power facilities.

2. Statement of the Problem and Approach for Its Solution

Let the stationary scene of the reactor core be observed by a collinear digital stereo vision system. In the frame of each video camera gets a cell consisting of seven heat emitting assembly. Stereo position is fixed. The internal and external parameters of stereoscopic video cameras are coordinated and known. The position of each heat allocating assembly in the global system associated with the cell is known. It is required to determine the height of each heat emitting assembly from the stereopair of the obtained images in the global coordinate system, to determine the measurement errors. The statement of the problem is illustrated in Fig 2.

The axis $0z$ of the global coordinate system $0xyz$ passes through the center of gravity of the central heat emitting assembly denoted by the number 1. Other heads of the heat emitting assembly are also numbered. The axis $0z_1$ of the local coordinate system of the stereo vision system $0x_1y_1z_1$ also passes through the center of gravity of the central heat that generates the assembly and has a slope with respect to the corresponding axis of the global system by a known angle γ.

The scene is projected onto the photomatrix of each camera. Having a stereopair of images, it is necessary to reconstruct it in a global coordinate system with the subsequent evaluation of the height of each head of the heat of the releasing assembly.

The relationships for finding projections and reconstructions for a collinear stereo system are well known. In [5,6], the peculiarities of the operation of this system for the case of the use of digital photo matrices are considered.

Thus, to find the projections of the scene in stereopair images, it is necessary to convert the initial data about the position of the scene objects from the global coordinate system to the local one, to find the stereopair of the images. According to the received stereopair, to reconstruct it in the local coordinate system, with the subsequent transfer of the obtained reconstruction to the global coordinate system.

In contrast to the very costly task of finding the centers of gravity of each head of the heat of the releasing assembly along the contour, it is proposed to use the method of full three-dimensional reconstruction of the contours. Authors of the method of preliminary isolation on the images of the center of gravity themselves admit that the error can reach half the pixel value for each image and, respectively, double, if we consider a stereopair.

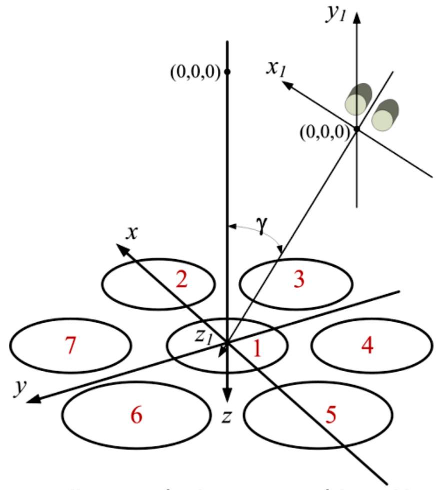

Fig.2: Illustration for the statement of the problem

Unlike the existing method, the height of each head of the heat of the releasing assembly is planned to be obtained through averaging the heights of the reconstruction points $\hat{z}_{l,i}$ of the corresponding contours.

$$\hat{z}_l = \frac{1}{k_l}\sum_{i=1}^{k_l}\hat{z}_{l,i}, \quad l = \overline{1,7},$$

where $\hat{z}_l$ is the average estimate of the height of the heat contour of the releasing assembly with the number l; k_l is the number of points in the contour taken for averaging.

The basis for this approach is the conclusion obtained in [6,7], where collinear digital stereoscopic systems show that errors for multiple measurements of different points with a certain limitation of their observation range have unimodal symmetric distributions with zero mean over all coordinates.

3. Model Experiment

In the model experiment, the following parameters of the digital stereo system were set: the stereo size - 0.25 m, the focal lengths of the lenses - 6 mm, the size of the photomatrix 1600x1200 pixels, the linear pixel size by height and width - 4 micrometers. In the line of produced digital cameras you can find a sufficient number of analogs for the construction of this stereo system.

As a model of the observed scene used cell of the seven heads of the heat releasing assemblies. The distance between the centers of gravity of the heads of the heat emitting assembly is taken equal to 3 meters, with the diameter of the head the heat emitting assembly is 2 meters. Different head heights within ± 0.02 m are simulated.

The distance of the observation was increased by more than 2 times compared to the actual observation distances and was 10 m. The axis $0z_1$ of the local coordinate system of the stereoscreen system $0x_1y_1z_1$ passed through the center of gravity of the central heat of the excretory assembly with an inclination angle γ relative to the corresponding axis of the global system of 30 degrees.

In addition to finding the average estimates of the height of the contours of the heat of the excretory assemblies entering into the cell for comparative analysis, estimates of the heights of the cen-

ters of gravity for each heat of the releasing assembly were obtained. This was done for a comparative analysis of the accuracy of the proposed method compared with the existing.
Figures 3 – 7 illustrate the stages of the model experiment. So in Fig. 3 the initial data are presented - a model of the heat contours of the assembling assemblies in the global coordinate system. The same model, represented in the local coordinate system of the stereo system, is shown in Fig. 4. The projections of the contours of the heads of the heat-releasing assemblies on the stereoscopic stereotypes with the matching of the stereopair are shown in Fig. 5. It can be seen that the location of the stereo system is chosen in such a way that the projections of all the heat-generating assemblies of the cell appear in the frame of each video camera. The found disparity of the projection points makes it possible to reconstruct the obtained images into a three-dimensional space for the local coordinate system (Fig. 6) and recalculated for the global coordinate system in Fig.7.

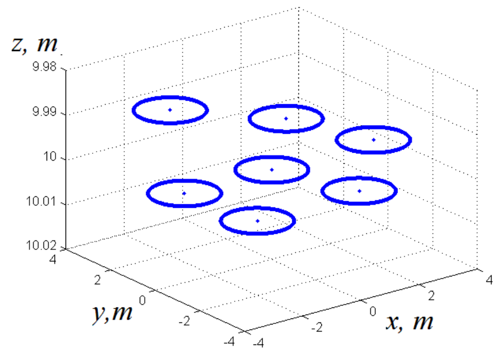

Fig.3: Model of the heat contours in the global coordinate system

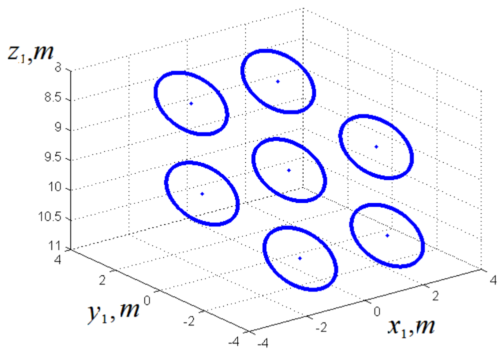

Fig.4: Model of the heat contours in the local coordinate system

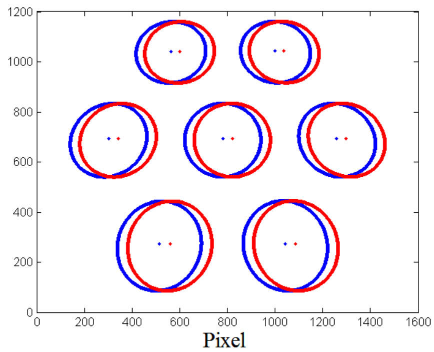

Fig.5: Combined stereopair of images

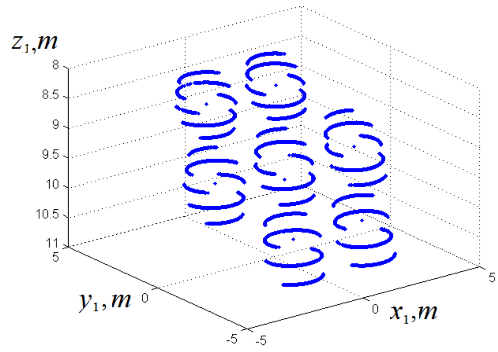

Fig.6: 3-D reconstruction in the local coordinate system

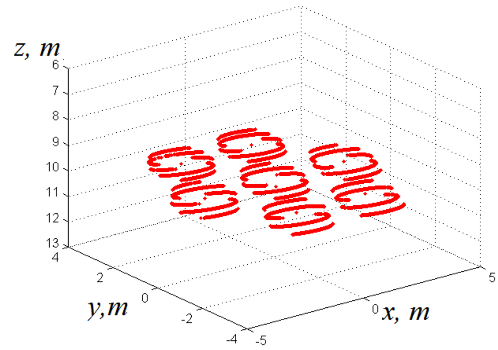

Fig.7: 3-D reconstruction in the global coordinate system

In the pair comparison of Fig. 3 and Fig. 7 or Fig. 4 and Fig. 6 it becomes obvious that the reconstruction has been made with errors, the causes of which lie in the discrete (pixel) representation of the stereopair images.
Table 1 shows the results of calculating the heights of the heads of heat-releasing assemblies. An analysis of the obtained calculation results indicates a higher accuracy in determining the heights of the heads of heat-releasing assemblies by the proposed method than with the determination of the centers of gravity on the stereopair images, and then reconstructing it in space.

4. Discussion of the Results

Computing showed a significant increase in the accuracy of determining the height of the heads of heat-releasing assemblies by the proposed method in comparison with the existing approach. It should be noted that these results were obtained for a stereopair of images obtained only for one fixed position of the stereo system. This circumstance again supports the proposed method, since there is no need to observe the scene from various angles.
As a negative point, we should note the complication of the CCTV system behind the reactor core, since a collinear digital stereo vision system is required to implement the method. At the same time, the issues of correct operation of such a system become more complicated, since it is necessary to carry out a set of measures aimed at accurate calibration of the stereo system, as well as monitoring the consistency of its parameters during regular work.
However, the gain in the accuracy of measurements and the ease with which altitude estimates are obtained suggest that the use of digital stereo vision systems is promising for contactless control of the heat of the releasing assemblies in the core of the reactor.

5. Conclusion

In the narrow sense of the interpretation of the results obtained, an obvious conclusion is the conclusion that the use of stereo vision systems for the noncontact control of the heat of the releasing assemblies in the reactor core is perspective.

In a broader sense of the interpretation of the results obtained, a method for obtaining accurate estimates for a number of inaccurate measurements (reconstructions) has been obtained and tested. This opens up good prospects for using the proposed method in various areas where measurements using digital stereo vision systems can be used. For example, in construction, where it is required to determine the heights of reinforced concrete piles used for the foundation. As altimeters for aircraft, where an accurate estimate of the altitude can be obtained from the contours of the ground situation (outlines of buildings, outlines of roads, rivers, field boundaries, etc.). In visual navigation systems for autonomous robotics, in particular in the problem of determining (clarifying) the distance to the obstacle along its contour.

Table 1. The results of calculating the heights of the heads of heat-releasing assemblies

Number of the contour of the head of the heat emitting assembly	Set head height, m	The calculated value of the height of the head along the center of gravity of the contour, m (existing method)	The calculated value of the head height from the average projection of the reconstruction points, m (the proposed method)	Comparison of the results obtained. Accuracy of height determination			
				existing method		proposed method	
				Absolute, m	Relative,%	Absolute, m	Relative,%
Contour 1	10	10.2008	9.9995	-0.2008	2.0079	0.0005	-0.0046
Contour 2	10.01	9.9821	10.0088	0.0279	-0.2787	0.0012	-0.0119
Contour 3	10.02	10.0152	10.0220	0.0048	-0.0479	-0.0020	0.0197
Contour 4	9.99	10.0133	9.9885	-0.0233	0.2328	0.0015	-0.0153
Contour 5	10	9.9800	10.0019	0.0200	-0.2003	-0.0019	0.0192
Contour 6	9.98	9.8694	9.9804	0.1106	-1.1082	-0.0004	0.0043
Contour 7	9.99	9.8717	9.9907	0.1183	-1.1841	-0.0007	0.0069

Acknowledgement

The work was prepared with the support of the Russian Foundation for Basic Research, projects number 18-08-01324 and 16-08-00752

References

[1] Kalyaev I. A., Rumyantsev K. E., Makeev V. V., Balabaev S. L., Korobkin V. V., Korovin J. S., Kuharenko A. P., Radetzky V. G., “Non-contact method for determining of the height of the heads nuclear reactor fuel assemblies on the basis of three-dimensional reconstruction images”, *Izvestiya SFedU. Engineering sciences*, Vol.3, No.80, (2008), pp.126–131.

[2] Makeev V. V., Povarov V. P., Korobkin V. V., Lebedev O. V. “The system of noncontact determination of the altitude difference in the heads of fuel assemblies in the reactor core”, *Izvestiya Vuzov. North-Caucasian region. Technical science*, Vol.16, (2006), pp.37–41.

[3] Balabaev S. L., Lozovskaya E. G., “The choice of camera position to minimize the measurement error of the fuel assembly head”, *Izvestiya SFedU. Engineering sciences*, Vol.8, No.169, (2015), pp.58–76.

[4] Konstantin E. Rumyantsev, Sergey L. Balabaev, Irina Yu. Balabaeva., “Fuel Assembly Height Measurements at the Nuclear Power Plant Unit Active Zone”, *Communications in Computer and Information Science*, Vol.712, (2017), pp.156 – 163.

[5] Rumyantsev K. E., Kravtsov S. V., “Analysis of measuring space stereoscopic digital television system. Point and interval estimation of coordinates of points of three-dimensional scenes”, *Electrical and information complexes and systems*, Vol. 3, (2011), pp.38–48.

[6] Rumyantsev K. E., Kravtsov S. V., “Analysis of measurement error of depth points of a three-dimensional scene stereoscopic digital television system”, *Radiotechnics*, Vol.9 (2011), pp.83–93.

[7] Kravtsov S. V., Rumyantsev K. E., “The Analysis of Measurement Capabilities Onboard Collinear Digital Stereo Vision Systems”, *2016 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2016 - Conference Proceedings*, pp.001597–001602. https://ieeexplore.ieee.org/document/7844467/ DOI: 10.1109/SMC.2016.7844467