APEM journal *Advances in Production Engineering & Management* 5 (2010) 1, 59 - 68
ISSN 1854-6250 Scientific paper

COMPUTER-BASED WORKPIECE DETECTION ON CNC MILLING MACHINE TOOLS USING OPTICAL CAMERA AND NEURAL NETWORKS

Klancnik S. & Senveter J.
University of Maribor, Faculty of Mechanical Engineering,
Smetanova 17, 2000 Maribor, Slovenia
E-Mail: simon.klancnik@uni-mb.si, jernej.senveter@uni-mb.si

Abstract:
In this paper, system for optical determining the workpiece origin on the CNC machine is presented. Similar high sophisticated systems are commercially available but in most cases they are very expensive and so their purchase is economically unjustified. The purpose of our research is to develop an inexpensive system for non-contact determination of the workpiece origin, which is also sufficiently precise for practical use. The system is implemented on a three-axis CNC milling machine Lakos 150 G, which is primarily designed for good machinability materials. Calibration procedure using feed-forward neural networks was developed. With this method the calibration procedure is simplified and the mathematical derivation of camera model is avoided. Learned neural network represents the camera calibration model. After neural network learning is complete, we can begin using the system for determining the workpiece origin. This developed system was through a number of tests proved to be reliable and suitable for use in practice. In the paper, working of system is illustrated with a practical example, which confirms the effectiveness of the implemented system in actual use on machine.

Key Words: Neural Networks, Image Processing, Milling, Workpiece Detection

1. INTRODUCTION

The use of machine vision systems is nowadays more and more present in the automation of industrial processes. These systems can be noticed, in particular, there where it is difficult or even impossible to implement automation through simple or conventional sensors, which are still considered to be more reliable. The machine vision is used for replacing human visual perception, as for example, product quality control, management of technological processes, laboratory analysis of images and similar. Thus, the reproducibility of procedures can be ensured, and the production costs as well as harmful effects of the production process on the environment can be reduced. Such systems help to improve competitiveness of technological processes.

Artificial vision is applicable as a sensor for managing of the system, ever since it imitates the human vision and allows contactless detection of the close vicinity of the industrial system. Since the first researchers in the area of the machine vision systems, describing the use of feedback loop of the artificial vision for the robot position correction and, consequently, the accuracy of the task performance, a considerable development of robot arms, controlled directly on the basis of artificial vision, can be traced. A number of systems of different makers manufacturing systems with fully integrated artificial vision system are available. Those systems are highly sophisticated and their price is high accordingly.

The article presents the development of the system for optical determination of workpiece origin [1] with the use of cheap equipment. The primary objective of our work was to develop a system for automatic determination of workpiece origin on the LAKOS 150G desktop milling machine, which will be less expensive than similar high sophisticated systems available on the market, and its performance will be sufficiently reliable and precise at the same time. The system was designed in way that it is possible to also use it on other machine tools, where it is necessary to determine the workpiece starting point.

The article is structured in way that first the applied hardware equipment is presented in short. Furthermore, the design of the system and the integration into the LAKOS 150G processing machine is presented in detail, as well as the basic principle of system operation. In order to obtain useful information from the image captured by the camera, it is necessary to process the image with appropriate algorithms for digital image processing. The procedure of image processing is presented in chapter four. The fifth chapter shortly presents the results of the operation of the system for a test example. The article ends with a short conclusion.

2. HARDWARE EQUIPMENT

The optical system for determination of the origin of the workpiece was implemented on the LAKOS 150G desktop milling machine, presented in Figure 1. The LAKOS machine is a desktop 3-axial CNC machine tool developed, in particular, as a teaching aid for educational institutions dealing with mechatronic systems. LAKOS is primarily designed for good machinability materials. It can be used for processing with cutting and operations like coating with adhesives or dyes, application of gaskets, and it can also be used as a robot system for measuring, testing or assembling. Since this is an education machine, its design is simple, thus providing more possibilities for the development of new applications and methods of use. The machine controls are performed by a personal computer equipped with Linux operating system, that is, through EMC2 open source CNC software package.

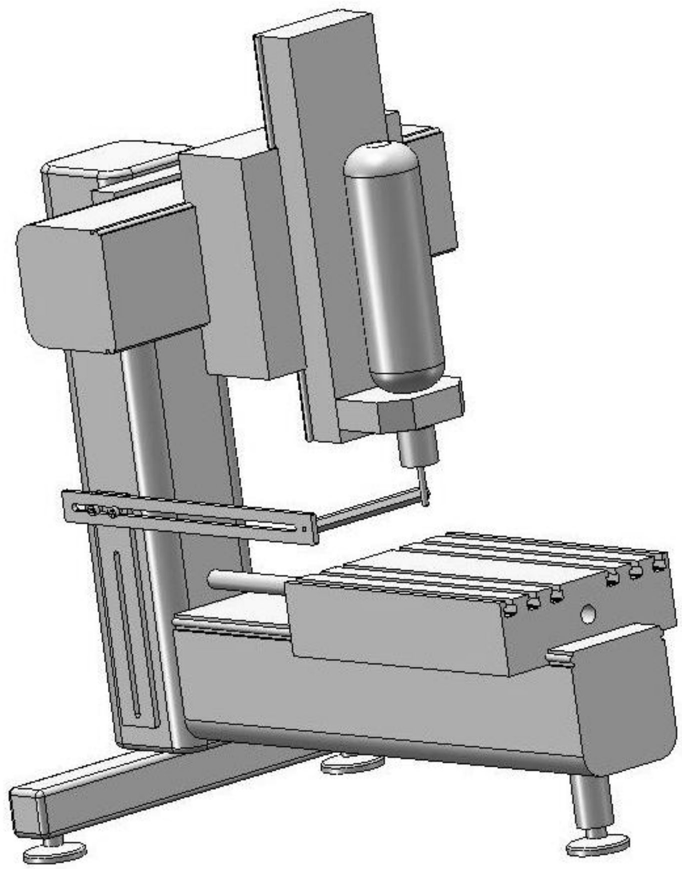

Figure 1: CAD model of LAKOS 150G desktop milling machine.

For the optical determination of the origin of the workpiece, it was necessary to place a camera on the machine. The camera has to be fixed; its position is not to be changed after the calibration of the system. For this purpose, the workshop of the Production Engineering Institute at the Faculty of Mechanical Engineering has manufactured a dedicated stand designed in way that the position of camera can easily be altered according to the requirements of the application using the camera (changing the distance of the camera from the observed object) (Figure 2).

An inexpensive QuickCam camera manufactured by Logitech (Figure 2) was used. This camera can capture up to 30 images per second. The maximum resolution, which can be attained by the direct capturing of the video signal, is 320x240 pixels. The capturing of the video signal on the personal computer is performed via the USB 2.0 interface, whereas the camera focus is regulated manually.

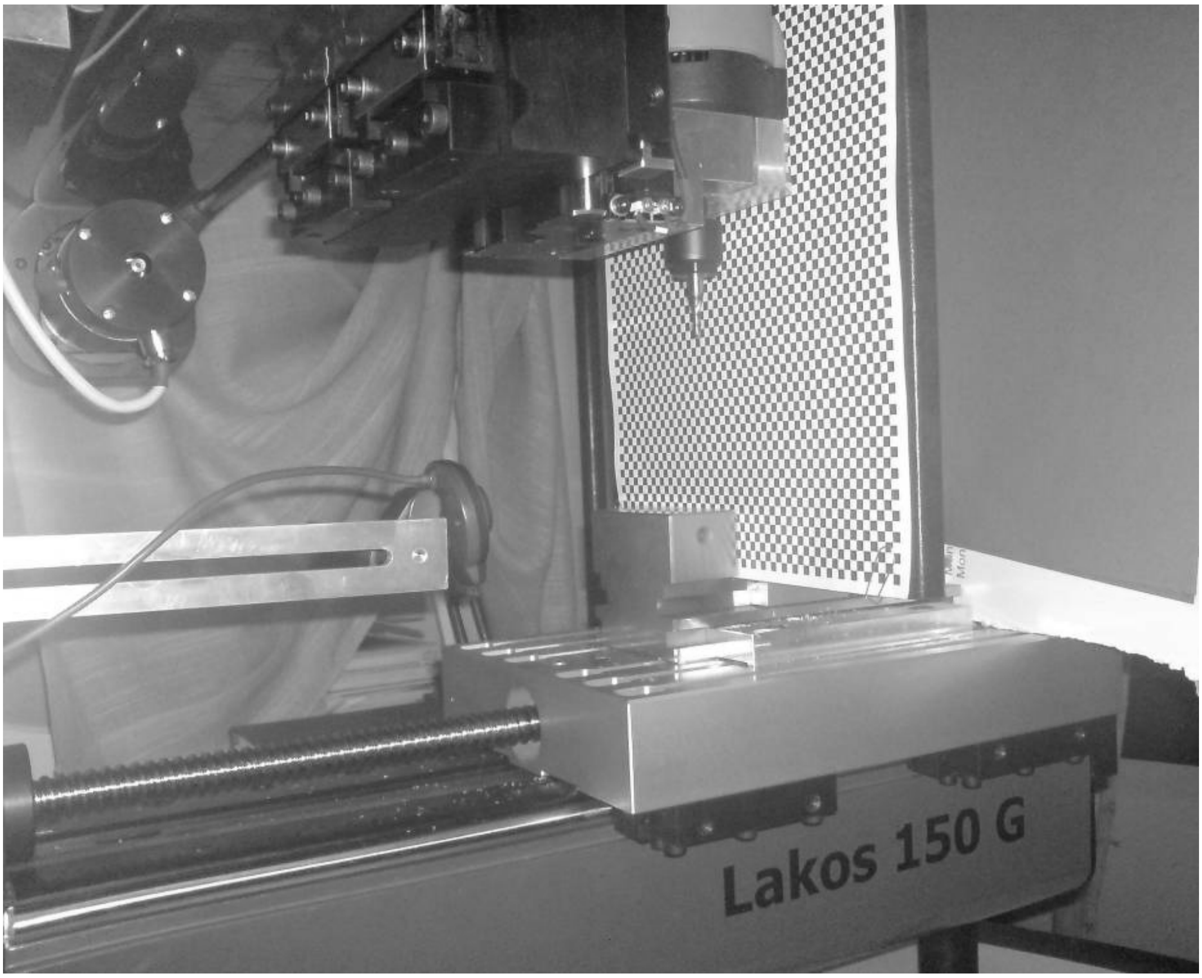

Figure 2: Stand holder for the camera and camera on the LAKOS 150G milling machine.

3. SYSTEM DESIGN

On the basis of the block diagram, the Figure 3 shows the principle of operation of the LAKOS machine, including the integrated optical system. When the workpiece is inserted and fixed, the system for optical determination of the origin [2] is started first. With help of the captured image, coordinates of the zero point of the workpiece are determined individually for each axis within the machine coordinate system. These values are saved in the “stepper.var” file, which is a system file of the EMC2 open source environment and is intended for saving variables, which have to be also preserved at the switch-off of the computer and at the next start-up of the application. When the file with the NC programme is loaded to the EMC2 environment, the coordinates of the zero point of the raw workpiece are read from the “stepper.var” file. Immediately after that, the processing with the LAKOS 150G can start.

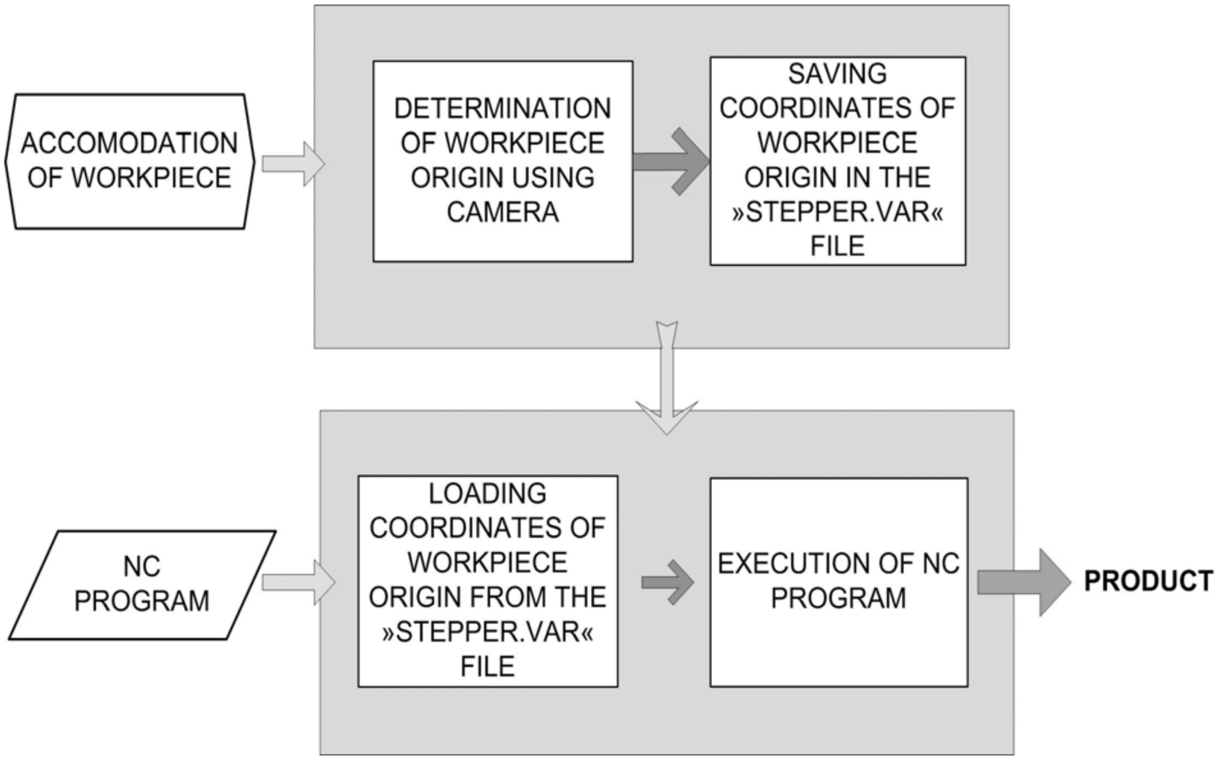

Figure 3: Basic principle of system working.

Figure 4 shows the block diagram of functioning of the module for optical workpiece positioning. Upon fitting the camera to the CNC machine, the system must be first calibrated in order to determine the relations between the coordinates in the captured picture and the robot space coordinates. The calibration process [2] has an especially important role in the machine vision systems aimed to give accurate measurements in real coordinates. Typically, the camera model consists of eleven parameters, namely six so-called external and five internal parameters determining the camera geometrical and optical properties and the camera positions and orientations relative to the outer coordinate system. After the calibration has been performed, it need not be repeated as long as the location of the camera on the robot does not change. In our case the camera calibration was implemented by means of artificial neural network. When learning of the neural network has finished, the use of the workpiece positioning system can start. Through camera the picture of the fixed workpiece is captured. In the next step the captured picture is processed by proper picture processing algorithms [3-9] by extracting from it the information about the position of three zero points of the workpiece in the captured picture. Those coordinates are the input information into the learned neural network having learnt in the stage of system calibration. The output from the neural network is the desired information, i.e., the workpiece position in the robot coordinate system.

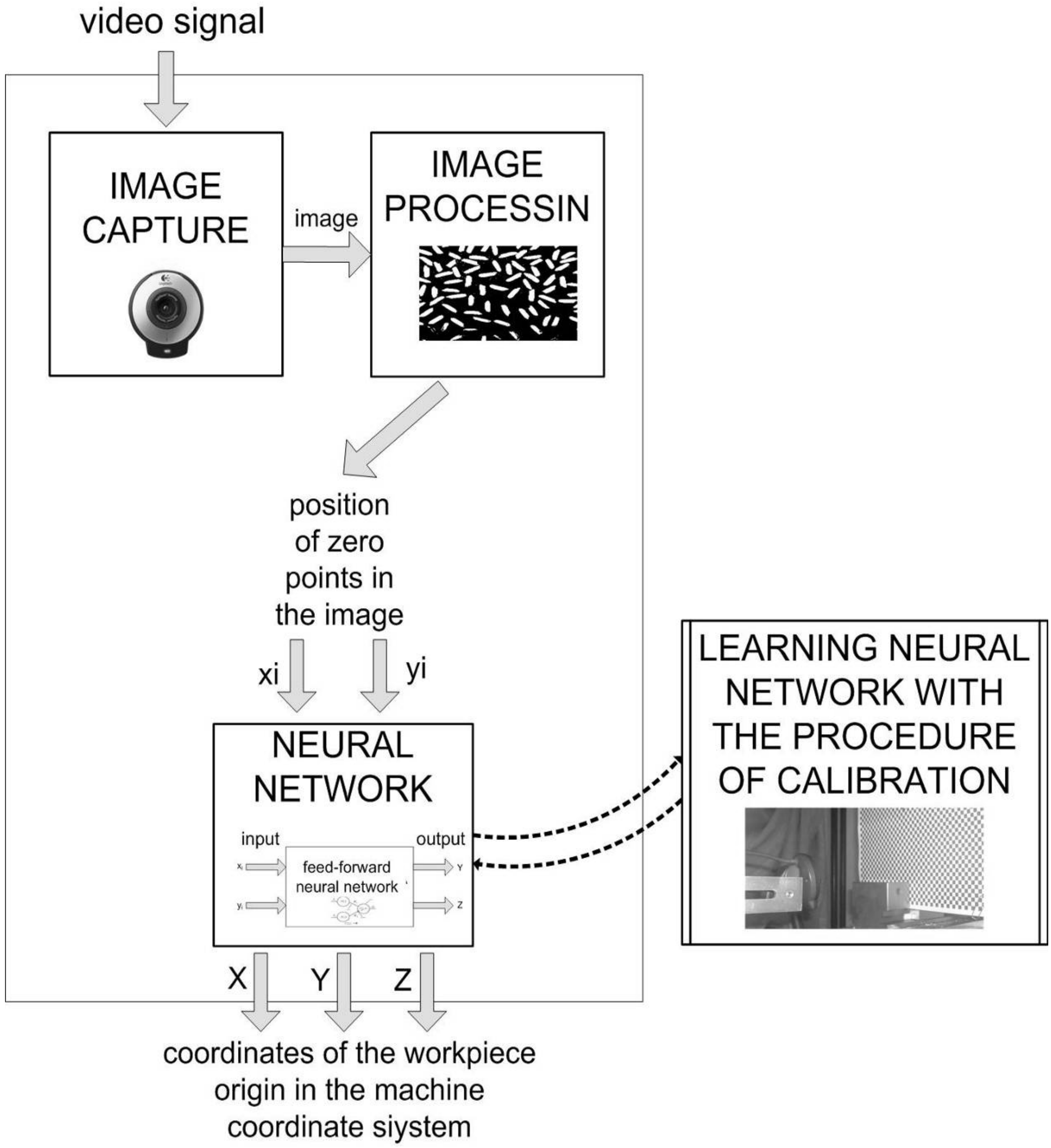

Figure 4: Block diagram of functioning of optical system.

4. IMAGE PROCESSING

By the use of the appropriate algorithms for digital image processing [3-9], the information that we are interested in can be obtained. In our case, the intention is to find an area in the image representing the workpiece origin (edge point of the workpiece). The Figure 5 shows the procedure of image processing.

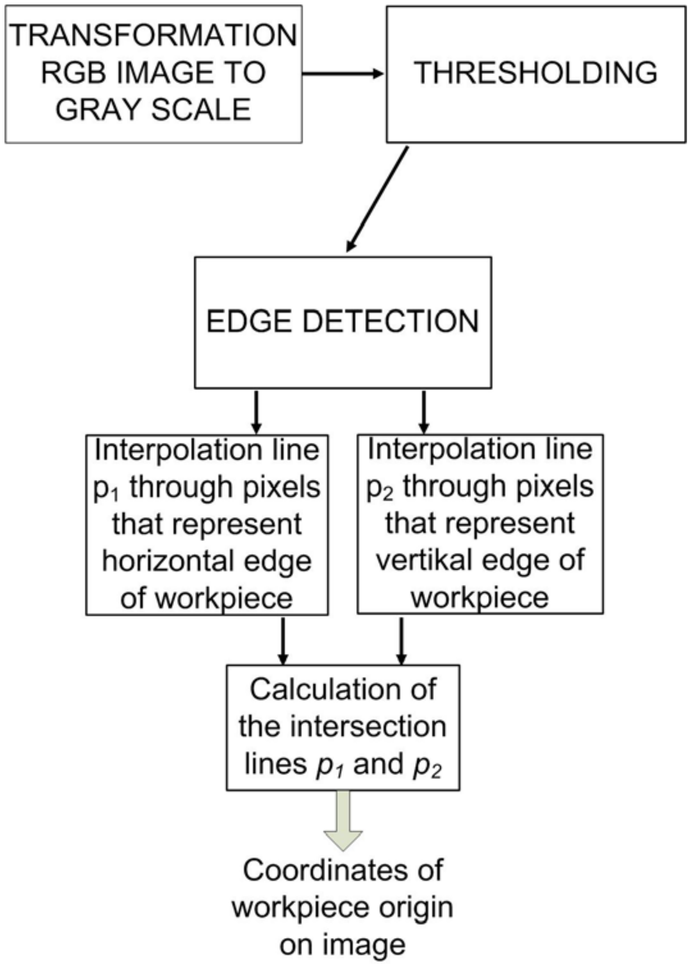

Figure 5: Block scheme of image processing.

Since in the present paper we will limit ourselves to monochromatic images, we have to transform the obtained colour images by using the transformation:

$$Y = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B \quad (1)$$

In the Equation 1 R represents red component, G represents green component and B represents blue component for each individual image element (from now on referred to as pixel), while Y represents the calculated grey scale value. In the next step, the object of interest is separated from the background. This is accomplished by using a threshold method [3]. This method enables us to separate the object of interest (in our case workpiece) from the background. The method is based on a comparison of the gray scale value of each pixel with a certain threshold value. If the gray scale value of the pixel exceeds the value of the threshold, we set the pixel value to 255 while pixels with gray scale value below the threshold value are set to 0. In this way we obtain a binary image with values 255 and 0. The efficiency of this method largely depends on the appropriate selection of the threshold value. We have chosen this value experimentally. Figure 6 represents a flow chart of the image processing employing the threshold method.

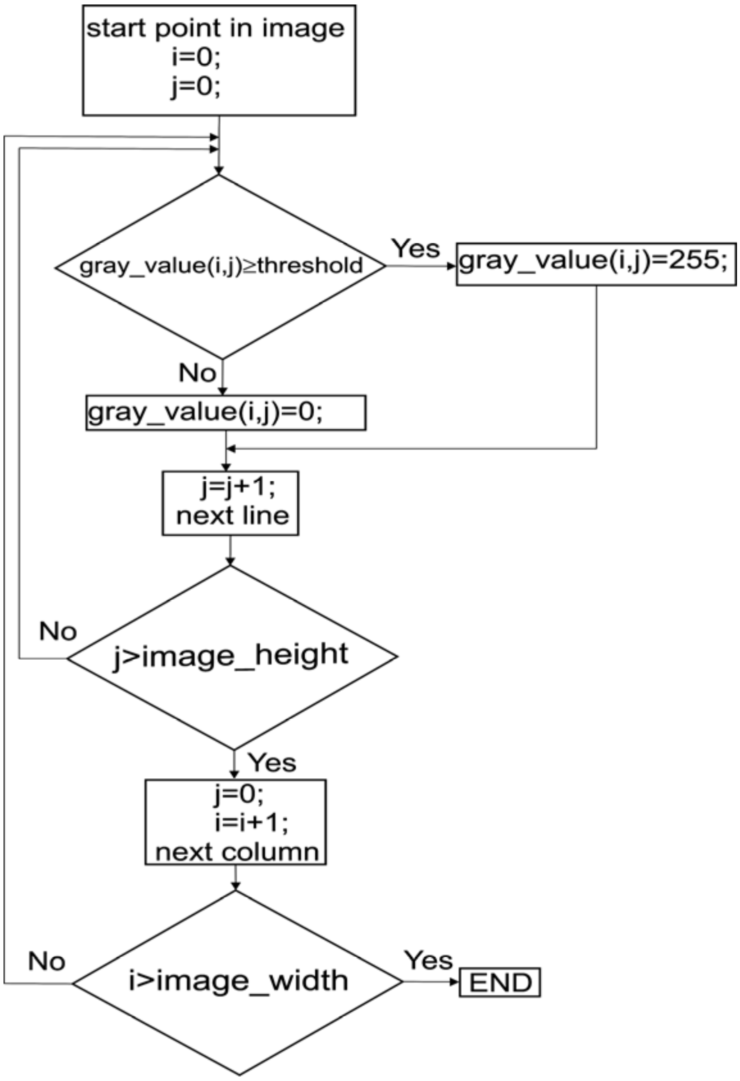

Figure 6: Flow chart of threshold method.

By using edge detection method we can define optical edges in an image. Edge in an image is defined by characteristic alterations of gray scale or colour component values in a specific direction. Our application uses the Sobel algorithm for the detection of edges [3]. This particular algorithm was chosen because our system is set in an environment where the impact of noise is minimal (unchanged scene) and thus making the Sobel detector robust enough for a reliable determination of edges in the image.

5. RESULTS

The system was tested with different workpieces of prismatic shape. In the continuation, the results of the system operation for the test workpiece are represented, with optional insertion of the workpiece in the worktable of the LAKOS milling machine (Figure 6).

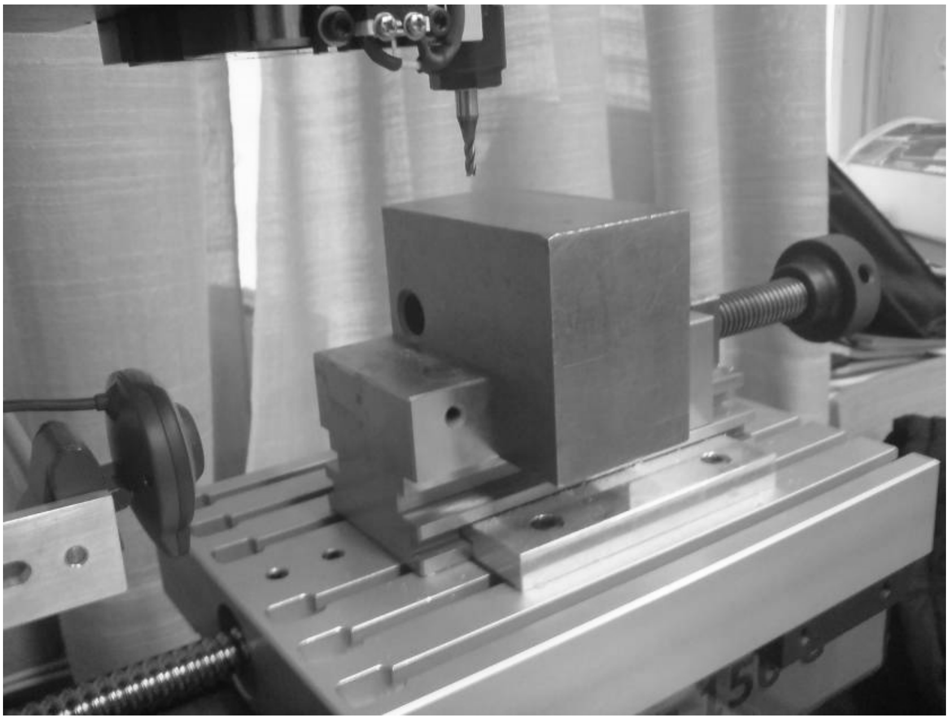

Figure 6: Test workpiece inserted in the LAKOS 150G milling machine.

First, the calibrated camera captures the image of the workpiece. The image is processed with the threshold method. Thus, we separate the searched object from the background. The result of the image processing with the threshold method is presented in Figure 7, where the white colour marks the searched object (workpiece) and the black colour the background.

Figure 7: The image is processed with the threshold method.

The Figure 8 shows the results of image processing with Sobel' edge detection algorithm. The detected edges of the workpiece are marked with white colour.

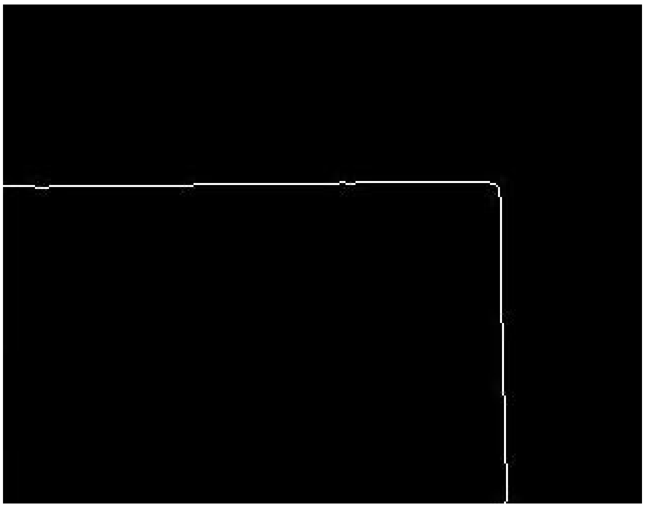

Figure 8: The image is processed with Sobel' edge detector.

The final result of digital processing of the captured image is the determined zero point of the workpiece in the image. The zero point determined by the implemented processing algorithm for the selected test example is shown in Figure 9.

Figure 9: Determined coordinates of the zero point.

It is evident from the Figure 9 that the system determined the coordinates of the zero point (x=249.0 and y=88.2) within the coordinate system where the starting-point is set in the upper left corner of the image. These two values represent the inputs to the neural network, which was taught at the stage of calibration, and its knowledge represents the relation between the coordinates of the image and the coordinates of the machine. The output from the neural network is thus the position of the workpiece zero point within the coordinate system. In the presented test example, the system determined that Y=22.8 mm and Z=92.7 mm. The tools of the machine were moved into that point, where it was established that the system precisely determined the zero point of the workpiece. With the used camera with resolution of 320x240 pixels, it can be theoretically determined the zero point of the workpiece to 0.3 mm precisely at the use of the system on the LAKOS machine (depending on the distance between the installed camera and the observed object). Use of the camera with higher resolution can improve the accuracy of the system.

6. CONCLUSIONS

The developed system for optical workpiece positioning has proved throughout numerous tests to be reliable and adequate for use in practice. The workpiece surroundings remain usually unchanged or single-colour base can be placed in position so that the workpiece is simply distinguished from the background and that the system functioning is reliable and robust. In the future a proper light source will be provided on the machine to illuminate the workpiece and its vicinity uniformly and continuously. Thus, the reliability of functioning of the system in different environments with different illumination of the space (surrounding) will be increased. It can be summarised that the presented system is reliable and effective for the use on the LAKOS 150G milling machine. Likewise, it can be concluded that the system is also appropriate for the use on other processing machines and devices where it is necessary to make a determination of the position of the workpiece.

REFERENCES

[1] Pahole, I., Ficko, M. (2004). Programming of NC machine tools, University of Maribor, Faculty of mechanical engineering, Maribor

[2] Kamnik, M., (2008). Use of the machine vision in adaptable manufacturing systems, master degree, University of Maribor, Faculty of mechanical engineering, Maribor

[3] Gonzalez, R. C.; Woods, R. E. (1993). Digital Image Processing, Addison-Wesley, Boston.

[4] Iglesias, T.; Salmon, A.; Scholtz, J.; Hedegore, R. (2006). Handbook of Machine Vision, Wiley-VCH, Weinheim

[5] Image processing fundamentals, Available from: www.ph.tn.tudelft.nl/Courses/FIP, Accessed on: 14.4.2009

[6] Klancnik, S., Balic, J. & Planincic, P. (2007). Obstacle detection with active laser triangulation, Advances in production engineering & management, Vol. 2, Issue. 2, p. 79-90

[7] Klancnik, S. (2006). Obstacle detection with structured light, Proceedings of the 15th International Electrotechnical and Computer Science Conference ERK'06, Portoroz

[8] Canny Edge Detection Tutorial, Avtor: Bill Green (2002), Available from: http://www.pages.drexel.edu/~weg22/can_tut.html, Accessed on: 14.4.2009

[9] Liang, R. L.; Basallo, E.; Looney, C. G. (2001). Image Edge Detection with Fuzzy Classifier, proceedings of the ISCA 14th international Conference, Las Vegas