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ACCURACY OF THE VISUAL MEASUREMENT SYSTEM OF BENT PIPES

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Abstract: *The paper presents a solution designed to increase the measurement accuracy of the vision system for the large-sized bent pipes with one fixed camera. For this purpose, a model of perspective distortions has been developed for the outline of the object's shape observed by the camera. Efficacy of the model was examined through a series of experimental measurements and their comparison with the model measurements of the pipe made on the coordinate measuring machine. During research, two versions of the program were used in parallel, where only one took into account the perspective distortions. The studies have confirmed the legitimacy and effectiveness of the used model improving the accuracy and repeatability of the measurement.*

Keywords: Vision system, Measurement, Pipes, Camera, Measurement accuracy.

1. Introduction

Modern vision systems are successfully widely used in our lives. They help us get to work through the traffic analysis (Beymer et al., n.d.) and control of the road signalling. They inform us about the amount and location of free parking spaces. They enable the autonomous car drive, and they watch over our security while shopping and they lead the shopping cart behind us.

As a result of the dynamic development of the machine vision, cameras replace an increasing number of sensors on the production lines. They are used for identifying materials, tools and products, recognising the presence, quality control of the products (Hongbin Jia et al., 2004), or correctness of technological operations. They support engineers while conducting research (Takosoglu et al., 2016) and experiments (Blasiak et al., 2014). They are also successfully used for the dimension and shape control of the produced elements. This work has described the measurement and control system for the large-sized bent pipes. Their measurement while using other alternative methods, due to the size and weight, is a complex and laborious task. The following sections describe the concept of the measurement stand, applied solutions and they present the results of preliminary measurements.

2. Methods

The examined measurement stand has been designed for the requirements of the company dealing with the manufacturing of bent pipes with diameters up to 1 meter. Between the successive stages of processing, the pipes are moved between the positions using a gantry. The prepared position will be placed over the existing measuring table in the factory. The application of a contactless, optical measurement method will not affect the reduction of the transport and working space. The measurement part used for the data acquisition will be placed over the mechanism of the gantry. Measurement data sent through Ethernet will be analysed by the software installed on the personal computer located in the design department, where the reports from the conducted measurements will also be generated. Fig. 1 shows the

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following parameters of the bent pipe subjected to control: pipe diameter D, bending angle γ, bending radius R, length of the straight sections l_1, l_2.

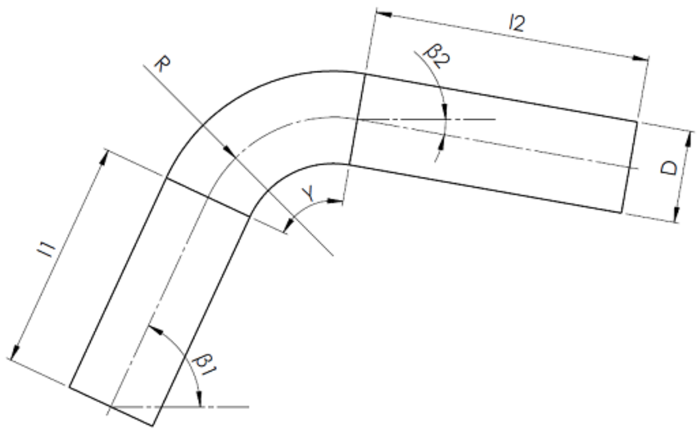

Fig. 1: Controlled parameters of the bent pipe.

Modelling the sources of distortion

The high-class stationary industrial camera with a lens with a fixed focal length matched to the working conditions is the measurement element. Parameters of the pipe are calculated from data obtained from a digital photography, which is processed and analysed by the prepared algorithms.

Numerous non-linearities associated with the geometry of the measuring system, the optical system of the camera and light-sensitive matrix and perspective distortions of the observed outline of the object have a negative impact on the accuracy and repeatability of the measurement results (Remondino and Fraser, 2006). In order to eliminate them, two mathematical models were developed. The first one, described in (Borkowski et al., 2016) allows the determination of the perspective projection of the edge of the perfect curved pipe on the table surface of the camera point. Due to the complexity, the analytical model is used after the appointment of the initial values. Fig. 2 shows a difference between a simple projection (red line) and a perspective projection (black line) on the table surface. Along with increasing the distance of the pipe from the centre of the table (optical axis of the camera) and its growing dimensions, the differences between contours are growing.

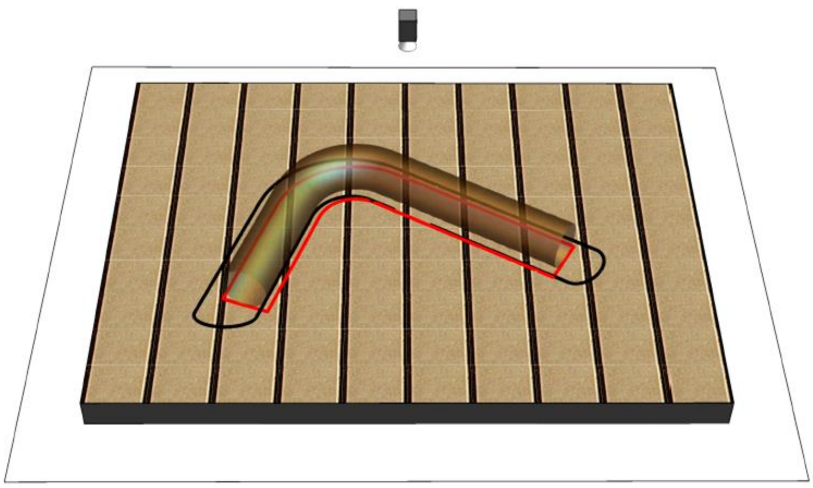

Fig. 2: The calculated contours of the pipe after the simple and perspective projections.

By matching the calculated projection of the pipe to the points of the pipe's edge in the picture, the algorithm obtains a higher accuracy and repeatability of the results on the entire surface of the measuring table.

The second mathematical model determines the relationship between the pixel coordinates of the digital image and the coordinate system associated with the measuring table. Its description included the inclination of the actual optical axis of the camera relative to the measuring table and the image sensor, different height and width of pixels in the matrix, as well as the lens aberrations, that is the radial and tangential distortion(Hartley and Zisserman, 2000). The process of determining the parameters of the model is called the calibration of the camera. The paper model has been prepared in order to perform the calibration, on which the squares with the same lengths of the sides were printed. Based on the points read out from the model placed in several positions, so that the entire surface of the measuring table was covered, the parameters of the model are calculated. Fig. 3 shows the straightened image along with the selected and adjusted contour of the pipe.

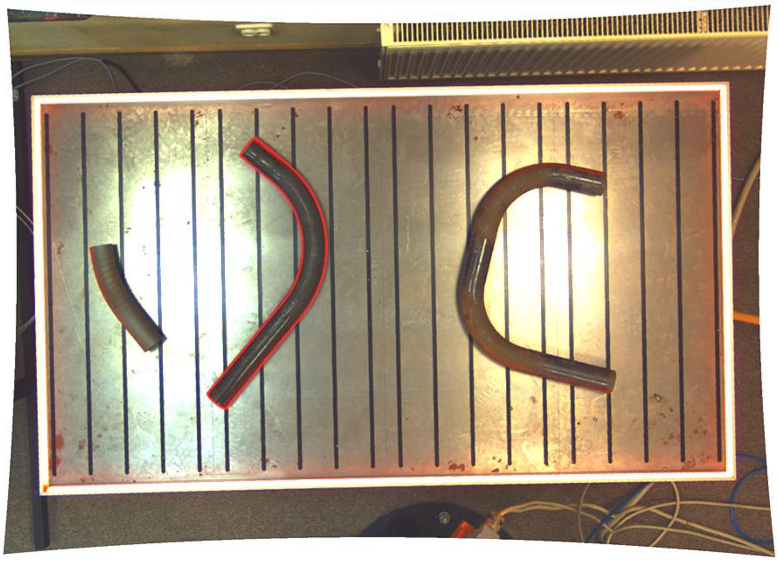

Fig. 3: The image straightened with the calibration camera model.

Comparative studies

For the purpose of the preliminary measurement accuracy assessment of the position, the model measurement of the curved pipe was conducted on the Prismo Navigator coordinate measuring machine of the Zeiss company. Based on the collected outlines of the pipe's edges, the surface model of a perfect pipe has been adjusted in the middle of its height. Then, a series of 10 measurements for this pipe with different position and orientation on the measuring table was performed, during which two versions of the program were used at the same time for data processing. The first one has additionally used the model describing the perspective distortion of the projection of the pipe's edge with respect to the camera point. The measurement results are presented in Tab 1.

Tab. 1: Summary of the measurement results for the bent pipe.

Measured parameter	Model measurement	Series of measurements with the perspective model		Series of measurements without the perspective model	
		Average value	Standard deviation	Average value	Standard deviation
Pipe diameter [mm]	60.8	60.1	0.2	60.2	0.7
Bending angle [°]	89.9	90.1	0.3	90.1	0.3
Bending radius [mm]	238.6	238.9	0.7	242.2	1.6
Length of the 1 straight section [mm]	296.4	295.9	1.1	304.2	2.7
Length of the 2 straight section [mm]	100.9	100.4	1.9	104.4	1.0
Length of the centre line [mm]	771.5	772.1	1.7	789.4	2.4

When analysing the parameters, it should be taken into account that the pipes during the bending process becomes oval, and the actual bending radius is a composite of many different arcs. Therefore, the length of the pipe's centre line was calculated on the basis of the measured values, which can be interpreted as the total length of the pipe.

3. Conclusions

The obtained results confirm the validity of the application of the perspective model. For the measurement series, parameters such as: the bending angle, or the length of the straight section were determined with the accuracy of about 1mm, while without taking into account the perspective distortion, the mean error was 4 times greater. In the case of the pipe's diameter, the smallest dispersion of results of the measurements was observed and almost a constant amount of errors, which may indicate the inaccurate determination of the pipe's edge points. The biggest differences were shown by an additional parameter – the length of the centre line, for which the mean error, after taking into account the perspective distortions, proved to be even several times smaller. In addition, this indicator has shown a high efficiency and repeatability of the measuring system, despite the lack of possibilities to clearly determine the beginning and ending of the arc.

The developed system is competitive towards other modern methods, it offers a fully automated, contactless and fast measurement process, it does not require proper orientation and referencing of the object, as well as it allows the simultaneous measurement of several pipes located on the scribing table. The measurement errors obtained by the system in the conversion into image coordinates amounted to about 2 – 4 pixels. The use of the vision systems on technological lines as control and measurement devices will enable the introduction of quality control as a continuous, automated, comprehensive and integral production stage.

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