Measurement 94 (2016) 254–264

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Image-based measurement of the dimensions and of the axis straightness of hot forgings

Aneta Zatočilová *, David Paloušek, Jan Brandejs

Institute of Machine and Industrial Design, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic

ARTICLE INFO

Article history:
Received 27 April 2016
Received in revised form 19 July 2016
Accepted 21 July 2016
Available online 22 July 2016

Keywords:
Forging
Quality control
Dimensional measurement
Shape measurement
Image-based measurement
Edge detection
Image processing

ABSTRACT

Non-contact measurement of shapes and dimensions is currently quite a common issue. A lot of systems with different speeds and accuracies are in the market. Measurement of high temperature objects is, however, a very special task which ensures a specific solution. This paper presents a measurement system composed of two high resolution single-lens reflex cameras and a software application, which is designed for the fast measurement of shapes and dimensions of rotationally symmetric forgings. The software computes the length, diameter, and straightness of the axis, based on a 3D model constructed from four boundary curves of the forging captured in two images. Experimental measurements have shown an error of up to 2% for the length measurement and 1% for the diameter measurement. Results are available in a few seconds. The proposed measurement approach based on boundary curves shows a great potential for practical use in forging plants.

1. Introduction

Forgings with a rotationally symmetrical shape are used to manufacture shafts for a wide range of mechanical devices. These semi-finished products are among the most commonly produced commodities in heavy industry. They are made by open-die forging on a hydraulic press at a temperature ranging from 850 to 1300 °C. Part of the production process is usually the control measurement of the shapes and dimensions and straightening on a three-point press. In addition to the dimensions, particular demands are imposed on the cylindricity and the straightness of the axis. As the production of large forgings is very expensive, the demand for production efficiency is growing, along with the demand for accuracy of the shapes and dimensions of the forgings.

At the present time, most of the forging plants still use contact measurement with hand-held calipers or mechanical gauges. Contact measurement is dangerous for the operator, slow, inaccurate and the results are not complex. The quality and accuracy of the measurements depend strictly on the operator's skills and production downtime is required. In addition to the high temperatures, large dimensions, very rough measured surfaces, and the need for immediate results must also be considered when developing the measurement system. At present, non-contact shape measurement of high temperature objects is still very demanding task and only a few systems have been implemented in heavy industry.

Generally, non-contact shape measurement can be based on the time-of-flight (TOF) or triangulation method. The measurement system Lacam Forge, based on TOF, has been developed by the Ferrotron division of Minteq GmbH [1]. Lacam Forge uses a three-dimensional eye-safe laser scanning system especially designed for hot surfaces and the surrounding conditions of a steel mill. It is based on the principle of evaluating the time response of modulated signal. Another system based on TOF is 3D Portal [2] from Mermec Group, founded in 1988. In addition to the measurement of dimensions and straightness, it also provides measurement of the entire surface and thus the result in form of 3D model. Development of TOF system with two-degree-of-freedom spherical parallel mechanism, which controls the movement of the lasers, has been described by Tian et al. in 2009 [3] and 2011 [4].

The triangulation method requires finding the matching points in two images, captured from different directions. In the case of active photogrammetry, light projection ensures the coding of individual pixels and their assignment. Nevertheless in the case of a heated surface, the standard illumination is not sufficient. The problem with using a triangulation method to measure hot forgings was solved by a research group around Jia and Liu [5–7]. The proposed system consists of two monochrome CCD cameras, a xenon lamp, and a computer. The cameras are equipped with filters that transmit only a narrow spectrum of shorter wavelengths.

* Corresponding author.
E-mail address: zatocilova.a@fme.vutbr.cz (A. Zatočilová).

http://dx.doi.org/10.1016/j.measurement.2016.07.066
0263-2241/

The spectrum selective method ensures the visibility of fringes projected on the surface of a heated forging. Unlike conventional contactless fringe projection scanners, the determination of homogeneous points in both images is not ensured by the *dynamic fringe projection (the phase-shift method) or* coded light method [8]. The article presents an algorithm for extracting of homogenous points, which lie in the middle of each projected fringe and on the interface of forging with the background. Experimental measurement of the length dimension of a steel board performed in laboratory conditions shows an error on the order of millimeters (less than 0.7%). Results presented by Jia at al. showed great potential of this approach based on active triangulation, xenon light and spectrum selective method.

Both the system with xenon light and the systems based on the TOF method require rotational movement of the forging during the measurement of straightness or shape. In both cases the accuracy of the measurement is on the order of millimeters, which is sufficient for the purpose. Systems based on the TOF method are flexible and very well suited to high-temperature measurement. The main advantage is the possibility of measuring directly in the forging machine. They allow the entire surface to be acquired, with the rotary motion of the forging ensured by a manipulator. However, this option is not often used because of the very slow scanning speed. The core of TOF systems is precise instrumentation which is generally very expensive in comparison with that required for photogrammetry systems using the triangulation method.

Jia et al. have proposed reconstructing the shapes and dimensions of geometrically simple objects based on detected edges. If the passive photogrammetry approach (measurement without added illumination) is to be used, the fundamental task is, first of all, to create good quality images for the purpose of image analysis. This problem is addressed in an article of Dworkin and Nye [9]. A method using edge detection to measure forgings has been proposed by Hu et al. [10].

Like those based on TOF method, systems based on the triangulation method have their pros and cons. On the one hand, some conditions for measuring the forgings are very specific and difficult to fulfill, and on the other hand, some of them can be used to simplify the measurement methodology. Simple shapes of forgings, less demand for accuracy (due to large scales present on the surface), and high contrast of forging in a heated state are some examples of the latter.

This article presents a measurement approach based on passive photogrammetry and edge detection that exploits the shape of the measured forgings. The passive photogrammetry method is generally unable to acquire the entire geometry of the object. However, it could be a simple, fast and inexpensive means for non-contact measurement of the straightness and dimensions of forgings with simple shapes.

2. Proposed measurement system

2.1. Measurement approach and system setup

The proposed measurement system is based on the assumption that the actual shape of these geometrically simple objects can be determined (in the simplest case) from four boundary curves which lie in two mutually perpendicular planes. The four boundary curves can be obtained by detecting the edges of the forging in two images. Fig. 1 shows the configuration of the system with two cameras. In the case of forgings with great length, measurement can be performed by using more cameras with parallel arrangement. The results would then be composed of multiple images.

Designing a measuring system requires solving four basic steps – camera calibration, detection and extraction of the entities searched for in the images, spatial orientation and calculation of the parameters to be determined. Diagram on the Fig. 2 shows the algorithm that explains the functioning of the system. The system is designed to be passive, on-line, noncontact, multi-image, and stationary. The current version uses two Canon EOS 500D single-lens reflex cameras with a resolution of 15.1 MPix.

2.2. Camera calibration

First step is correction of radial distortion in images. Correction algorithm was adapted from Jaap de Wries and taken from Matlab central database [12]. Next step is calculation internal and external parameters of cameras. Because the cameras must be mounted on tripods at a height of several meters above ground, the calibration needs to be performed on a large and static scene. For this purpose, a calibration using a stable field of circular targets (also called reference points) and a simple and well-known direct linear transformation (DLT) [11,13] has been proposed. DLT requires knowledge of the 2D coordinates of at least seven points in image and their corresponding positions in space relative to a world coordinate system. The algorithm employed to search for the centres of targets uses a centroid method [14]. Once the centres are found, they are sorted, numbered, and assigned to the appropriate coordinates of the targets measured in 3D. The 3D coordinates are acquired using the professional photogrammetry system Tritop. The Tritop measurement needs to be done only once for each measured scene.

2.3. Image scale calculation

The scale in the image is calculated according to the equation $m = L/c$, where L is the distance of a point in space from the centre of projection of the camera, and c is the principal distance of the camera. Distance L is commonly calculated by the triangulation

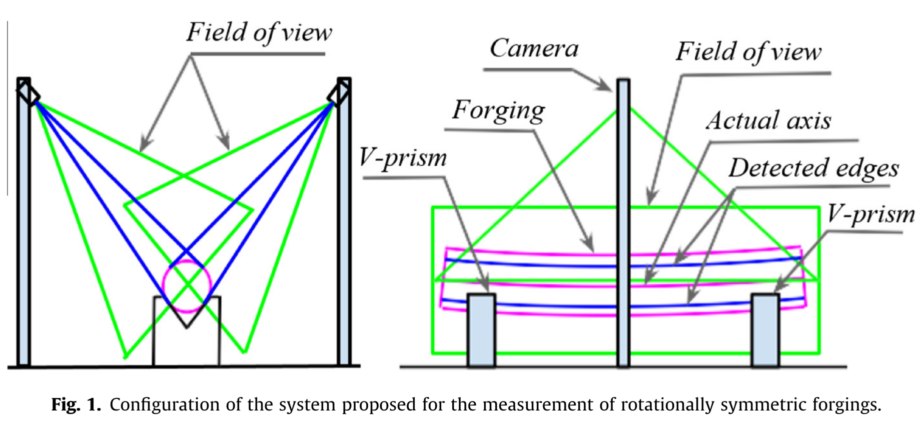

Fig. 1. Configuration of the system proposed for the measurement of rotationally symmetric forgings.