A Novel Method for Measuring the Length of Hot Large Forgings Based on Machine Vision System

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Research Article

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A novel method for measuring the length of hot large forgings based on machine vision system

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Abstract

Large forgings can be applied to manufacture key parts in large equipment used in petrochemical, shipbuilding, aerospace, nuclear industry. At present, the size of hot large forgings is mainly measured by hand-held calipers or mechanical gauges through contact measurement method. In order to realize non-contact length measurement of hot large forgings, a novel method for measuring the length of hot large forgings based on machine vision system is proposed. Firstly, the light strips are recognized according to the continuous characteristics of the light stripes in the image acquired by the hot forging dimension measurement system based on machine vision. Secondly, using the sub-pixel edge of light strips acquired by the improved sub-pixel edge detection algorithm, the three-dimension (3D) points of each edge of light strips are calculated, respectively. Lastly, the two-dimensional (2D) points projected from the 3D points onto the fitted plane are used for curve fitting, and the edge of hot part corresponding to each light strip edge is calculated according to the curvature of the fitted curves. The distance between the start point and the edge point on each light strip edge is considered as the length of hot forging at the corresponding edge of each light strip. The length measurement experiment shows that the method can be used to calculate the length of hot large forgings. The measurement error of the length measurement system when measuring part at room temperature is 0.547%. The time for measuring the length of hot forging is 6.8s.

Keywords: Hot large forging; Open die forging; Length measurement; Machine vision

1 Introduction

Large components are the critical components of manufacturing large equipment, which are widely applied in the field of nuclear power, petrochemical, shipbuilding, aerospace. Open die forging is usually employed in the manufacturing process of large components. The dimension of hot forging in most factories is still measured by operators with hand-held calipers, mechanical gauges. As the temperature of hot forging can reach 1000°C, the contact measurement method is dangerous to operators. In order to avoid the potential harm to the operator, some research work on non-contact dimension measurement of hot forging has been carried out. The dimension measurement methods of hot forgings are mainly divided into laser scanning method and machine vision method.

A lot of research works have been done to measure the diameter of hot forging using the laser scanner. LaCam-Forge measurement system of hot large forging was developed by *Rech et al.* [1]. A laser scanner is used in the measurement system to obtain point cloud data for acquire the 3D model by scanning the surface of the forging several times. China First Heavy Industry Corporation (CFHI) have applied a laser scanner to obtain the three-dimensional information of the cylindrical forging surface [2]. The dimension information of the cylindrical forging is obtained by calculating the section using the data from laser scanning. *Du et al.* [3] propose a field measurement method of high temperature large forgings based on two-dimensional laser radar. The Two-dimensional laser radar is driven by the servo motor to scan the surface of the measured forging and obtain the point cloud data. After the three-dimensional model of the forging is obtained by three-dimensional reconstruction using the point cloud data, the size of the forging can be measured. A method of processing laser scanning data of radial section dimensions for ring forgings is proposed by *Fu et al.* [4-6]. The laser scanner scans the radial uppermost layer section of the ring forging horizontally. When the laser irradiates the surface of the revolving ring forging, the laser scatters and returns to the laser detector. The laser detector sends the information to the computer. Then, the coordinates of laser hitting points are obtained by the computer. Because the scanning angle of the laser is limited and the ring forging is in a rotating rolling process, the forging needs to be scanned many times. *Bokhabrine et al.* [7] developed a system based on two Leica ScanStation2 TOF laser scanners for the measurement of the diameters of hot cylindrical metallic shells in the forging process. The Leica Scan Station2 is a TOF 3D scanner designed for large scene survey. Measurement is performed with a pulsed green laser. The TOF laser scanners is placed more than 15m away from the hot shell to acquiring accurate point cloud from which three-dimensional views of the shell can be reconstructed and diameter measurements done. A 3D laser scanning system based on spherical coordinates which can be used to measure the

diameter and length of hot forgings has been developed by *Gao et al.* [8-9]. The system consists of a time-of-flight (TOF) laser radar, a scanning device of the two-degree-of-freedom (2-dof) spherical parallel mechanism (SPM), and two motors with controllers. The spherical parallel mechanism can drive the time-of-flight laser radar to move as a theodolite for 3D scanning. By processing the three-dimensional data of forging surface which are obtained by scanning for a few times, the diameter and length of hot large forging can be measured.

A lot of research work has been done in obtaining the image of hot forging and measuring the diameter of hot forging by machine vision system. *Dworkin et al.* [10] use CCD camera to acquire image of forgings. Experimentation is performed to evaluate the effectiveness of three different modes of image acquisition, namely the use of monochrome images in visible light, color images in visible light and monochrome images taken with an IR-pass optical filter. The experiment result shows that the near-IR images can acquire reliable image processing. This method can be used to find the edge of forging. *Jia et al.* [11,12] used the spectrum selection method to obtain the image of hot large forgings by eliminating the light radiated from forgings. The diameters of hot large forging can be calculated by acquiring the structure light projected on the forging surface. A vision measurement system for hot large forging is developed by *China First Heavy Industries (CFHI)* [13,14], which is composed of CCD camera and mobile platform. The CCD camera is fixed on the mobile platform and can move with the mobile platform. When measure the dimension of hot large forgings, the edge of the forging is detected from the image taken by the CCD camera, and the size of hot large forging is determined by the moving distance of the mobile platform. The diameter of cylindrical forging can be measured by moving the platform up and down, and the length of forging can be measured by moving left and right. *SHANGHAI ELECTRIC GROUP* [15] has developed a dimensional measurement system for stepped shaft forgings. The measuring system consists of two sets of equipment, each of which includes a CCD camera and a line laser. Each set of measuring system is used to collect the three-dimensional information on one side of the forging. After synthesizing the three-dimensional information on both sides of the forging, the size of the stepped shaft forging can be obtained. A diameter measurement system for shaft forgings is designed by *Bi et al.* [16]. When measuring the diameter of forging, the laser ranging sensor and CCD camera move up and down together. The laser ranging sensor detects the upper and lower edges of the forging, and displacement sensor is used to measure the displacement distance to obtain the initial size of the shaft forging. After correcting the edge of the forging in the image taken by industrial camera, the actual diameter of shaft forging can be obtained. *Drago et al.* [17] developed a measurement system for on line measurement the diameter of cylindrical workpieces in precision open die forging. *Ghiotti et al.* [18] presents a coordinate measuring system for fast measuring dimension of freeform parts at elevated temperatures through high-speed laser triangulation method. The scanner which is consists of up to eight light-sectioning sensors acquire 2D cross-sections (xy-plane) of the workpiece by means of laser line triangulation. Each sensor, consisting of a line laser, a CMOS camera and optical bandpass filter, is arranged on an octagonal metrology frame to obtain complete profiles.

At present, machine vision system is mainly used to measure the diameter of forgings. A novel length measurement method of hot large forging based on machine vision system is presented in this paper. This paper is organized as follows: Section 2 describes the composition of the dimensional measurement system of hot large forging. The light strips recognition method is introduced in Section 3. In Section 4, an improved sub-pixel edge detection method and 3D reconstruction of light strips are discussed. Section 5 introduces the length measurement method of hot forging. Section 6 is the conclusions.

2 Dimensional measurement system of hot large forging

The dimensional measurement system of hot large forging is shown in Fig. 1. The dimensional measurement system is mainly composed of monochrome CCD camera (Redlake ES4020), projector (3M PD80X), short-wavelength pass filter (the cut-off wavelength is 450nm) and data processing equipment (Lenovo M425). The resolution of monochrome CCD camera is 2048×2048 . The short-wavelength pass filter is installed in front of the lens of each monochrome camera to filter the light radiated by hot forging. Because the shape of the light strips projected by the projector can be changed easily which can meet the requirements of dimensional measurement of hot parts with different shapes, the projector is selected to project light strips in the dimensional measurement system. For measuring the length of hot forging, the projector is employed to project transverse light strips on the surface of hot part.

Fig.1 Dimensional measurement system for hot large forging

Fig.2 shows the color image of the hot forging with a weight about 20 tons. Because of the strong light radiated by hot forging, the light strips projected on the surface of hot part in the image can hardly be identified.

Fig. 2 The color image of the hot forging with a weight about 20 tons

(a) Left image

(b) Right image

Fig.3 The images of hot large forgings acquired by the dimensional measurement system

The images of hot forging acquired by the dimensional measurement system are shown in Fig.3. Fig. 3a and Fig. 3b are images taken by the left camera and the right camera, respectively. In Fig.3, the light strips projected by the projector on the surface of hot forging are not affected by the light radiated by hot part. The light strips projected by the projector is represented by $n(W)$, where $W=1,2,L,5$. Thus, the light strips in the left image and right image is represented by $n_L(W)$ and $n_R(W)$ respectively.

3 Light strips recognition

The coordinate systems are established in Fig.3a and Fig.3b, respectively. In Fig.3a, the horizontal direction of the image coordinate system is the X axis and the vertical direction is the Y axis. The units of X and Y axis are pixels. The pixel in the upper left corner in Fig. 3a are represented as (1,1). The straight lines l_A and l_B are the two vertical lines in Fig.3a, and the distance between the two lines is δ pixels. Where, $\delta=100$ in this paper. The X-axis coordinate values of straight lines l_A and l_B are expressed as X_{l_A} and X_{l_B} , respectively. The values of X_{l_A} and X_{l_B} are needed to be preset according to the size and position of the hot forging. The value of each pixel within the range of lines l_A and l_B in Fig.3a is shown in Fig. 4. As can be seen from Fig. 4, the value of all pixels on the light strips within the range of l_A and l_B are larger than those of the background pixels.

Fig.4 The value of each pixel within the range of line l_A and l_B

(a) The values of each pixel on the line l_A

(b) The values of each pixel on the line l_B

Fig. 5 The values of each pixel on the lines l_A and l_B in Fig.3(a)

The value of the pixels on the line l_A and l_B in Fig. 3a are shown in Fig. 5a and Fig. 5b, respectively. In order to determine the peak of the light strips, the following inequality is employed:

$$\begin{cases} g(X, Y+e) \geq g(X, Y+e+1) \\ g(X, Y-e) \geq g(X, Y-e-1) \end{cases} \quad (1)$$

Where, X and Y are the abscissa and ordinate of the pixel (X, Y) , respectively; $g(X, Y)$ is the value of the pixel (X, Y) ; $e=1, 2, 3, 4$; X and Y are positive integers.

The peaks of the light strips on the l_A and l_B are calculated as follows:

Step1: The maximum value of the pixels in Fig.5(a) is determined and represented by $G_{\max}$. Let $G = \frac{G_{\max}}{3}$.

Step2: Set the value of the pixel with the value less than G in Fig.5a to zero, inequality (1) is used to determine whether the pixel (X_{l_A}, Y) is peak. Where, $Y \in [10, 2038]$.

If $g(X_{l_A}, Y)$ is not equal to zero, the value of e is substituted into inequality (1) in turn. If inequality (1) is true when e is equal to 1, 2, 3 and 4, (X_{l_A}, Y) is the peak. The number of peaks in Fig.5a is represented by M_{l_A} .

Step3: If $L_s \leq M_{l_A} < 2 \cdot L_s$, the peaks (X_{l_B}, Y) in Fig.5(b) can be calculated using the same method as in step 2. The number of peaks is represented by M_{l_B} .

Elseif $M_{l_A} > 2 \cdot L_s$, then repeat step 2 with $G = G + 5$ as the threshold.

Elseif $M_{l_A} < L_s$, then repeat step 2 with $G = G - 5$ as the threshold.

Step4: If $L_s \leq M_{l_B} < 2 \cdot L_s$, the calculation process ends.

Elseif $M_{l_B} > 2 \cdot L_s$, then repeat step 2 and step 3 with $G = G + 5$ as the threshold.

Elseif $M_{l_B} < L_s$, then repeat step 2 and step 3 with $G = G - 5$ as the threshold.

The values of the peaks on l_A and l_B are shown in Fig.5. The coordinates of the peaks on the l_A and l_B are expressed as $(X_{l_A}, Y_{l_A}(m_{l_A}))$ and $(X_{l_B}, Y_{l_B}(m_{l_B}))$, respectively. Where, $m_{l_A} = 1, 2, L, M_{l_A}$, $m_{l_B} = 1, 2, L, M_{l_B}$.

The light strips recognition steps are as follows:

Step1: Let $m_{l_A} = 1$ and $t_{rec} = 1$. Take the pixels $[Y - n_r, Y + n_r]$ on the $X_{l_A} + t_{rec}$ column. The coordinate of the pixel with the largest value are expressed as $(X_{l_A + t_{rec}}, Y_{l_A + t_{rec}}(m_{l_A}))$. Where, $n_r = 6$, $Y = Y_{l_A + t_{rec} - 1}(m_{l_A})$.

Step2: If inequality (1) is true when e is equal to 1, 2, 3 and 4, $(X_{l_A + t_{rec}}, Y_{l_A + t_{rec}}(m_{l_A}))$ is the peak on the $X_{l_A} + t_{rec}$ column. Where, $X_{l_A + t_{rec}} = X_{l_A} + t_{rec}$.

Elseif inequality (1) is false when e is equal to 1, 2, 3 and 4, then $(X_{l_A}, Y_{l_A}(m_{l_A}))$ is considered as the interference light. Let $m_{l_A} = m_{l_A} + 1$, $t_{rec} = t_{rec} + 1$ and repeat steps 1 and step 2.

Step3: If $t_{rec} < X_{l_B}$, make $t_{rec} = t_{rec} + 1$ and repeat steps 1 and step 2.

Elseif $t_{rec} = X_{l_B} - 1$, $(X_{l_A}, Y_{l_A}(m_{l_A}))$ is the peak of the light strip on the l_A column and expressed as $(X_{l_A}, Y_{l_A}(n_{l_A}))$. Make $n_{l_A} = n_{l_A} + 1$ and repeat steps 1, 2 and 3.

If the value of $n_{l_A} - 1$ is not equal to the number of light strips projected on the surface of hot forging, then both l_A and l_B are all shifted to the right by N_p pixels. Then, the steps of peaks calculation on the l_A , l_B and the steps of the light strips recognition are repeated. Where, $N_p = 120$. According to the hot parts position in Fig.3a, the initial value of X_{l_A} is set to 1330.

The light strips in the image acquired by the right camera shown in Fig.3(b) can be recognized in the same way.

4 Sub-pixel edge detection and 3D reconstruction

4.1 Sub-pixel edge detection

Canny edge detection operator is employed to calculate the pixel edges of the light strips projected on the surface of the hot forging. The edge of the light strips on the l_A can be acquired using the recognized light strips. In Fig.3a, the upper edge and lower edge of the light strip $n_L(W)$ in the l_A are respectively by $EU_{n_L(w)-l_A}$ and $ED_{n_L(w)-l_A}$, respectively. Take the edge of each light strip in l_A as the starting point, the upper edge $EU_{n_L(w)}$ and the lower edge $ED_{n_L(w)}$ of light strip $n_L(w)$ can be obtained by searching along the pixel edge.

An improved sub-pixel edge detection algorithm is applied to obtain the sub-pixel edge of structured light strip [19]. In order to calculate the sub-pixel edge corresponding to the pixel edge of the light strip in Fig. 3a, take the pixel within the 7×7 range centered on the pixel edge. Fig. 6 shows pixels in the range of 7×7 centered on one pixel edge. The coordinate system oxy is established with the center of the pixel level edge as the coordinate origin o , the abscissa as the x axis and the ordinate as the y axis. Since the structured light strip projected on the forging surface can be approximately regarded as a straight line, the pixels shown in Fig. 5 can be divided into two regions by a straight line. The expression of the line is

$y = ax + b$. Where, a and b are coefficients to be solved. The value of the pixel is represented by $gE(x, y)$. The center of gravity coordinates can be calculated according to the pixel value. The line between the coordinate origin o and the gray center of gravity is the normal of a straight line and is represented by N . Since the straight line $y = ax + b$ passing through the sub-pixel edge is perpendicular to the normal N , the slope a of the straight line can be obtained.

Fig.6 The pixels in the range of 7×7 centered on one pixel edge

(a) Left image

(b) Right image

Fig.7 The sub-pixel edges of light stripes

Fig.8 The enlarged view of the sub-pixel edge in the rectangular box in Fig. 7a

Let the pixel values in the upper region and the lower region of the straight line $y = ax + b$ be the same, and the pixel values in the upper region and the lower region of the straight line are represented by W_1 and W_2 , respectively. If the center of gravity is located in the second and fourth quadrants, the calculation formula of W_1 and W_2 is:

$$\begin{cases} W_1 = \frac{1}{6} \left(\sum_{k=0}^2 gE(x-3+k, y+3) + \sum_{k=1}^2 gE(x-3, y-3+k) + gE(x-2, y+2) \right) \\ W_2 = \frac{1}{6} \left(\sum_{k=0}^2 gE(x+3-k, y-3) + \sum_{k=1}^2 gE(x+3, y-3+k) + gE(x+2, y-2) \right) \end{cases} \quad (2)$$

If the center of gravity is located in the first and third quadrants, the calculation formula of W_1 and W_2 is:

$$\begin{cases} W_1 = \frac{1}{6} \left(\sum_{k=0}^2 gE(x+3-k, y+3) + \sum_{k=1}^2 gE(x+3, y+3-k) + gE(x+2, y+2) \right) \\ W_2 = \frac{1}{6} \left(\sum_{k=0}^2 gE(x-3+k, y-3) + \sum_{k=1}^2 gE(x-3, y-3+k) + gE(x-2, y-2) \right) \end{cases} \quad (3)$$

The sum of the values of the pixels in each column in the range of 7×7 is represented by S_η . Furthermore, the value of S_η can be represented by W_1 and W_2 . Where. $\eta=1,2,L,7$. Therefore, the intercept b of the linear equation $y = ax + b$ can be calculated according to the two expressions of S_η . The intersection of the straight line $y = ax + b$ and the normal N passing through the origin o is the sub-pixel edge corresponding to the pixel level edge.

The upper and the lower sub-pixel edge points of each light strip are sorted in the order of abscissa value from small to large, respectively. The sub-pixel edges of light stripe are shown in Fig. 7. The enlarged view of the sub-pixel edge in the rectangular box in Fig. 7a is shown in Fig. 8.

4.2 3D reconstruction

According to the map from each sub-pixel edge in left image to its corresponding epipolar line in the right image, the matching points can be obtained. The matching points are determined through the basic matrix $\mathbf{F}$:

$$\mathbf{E}U_{n_L(w)} \cdot \mathbf{F} \cdot \mathbf{E}U_{n_R(w)}^T = 0 \quad (4)$$

If the coordinate of $\mathbf{E}U_{n_L(w)}$ and $\mathbf{E}U_{n_R(w)}$ is expressed as $(XU_{n_L(w)}, YU_{n_L(w)})$ and $(XU_{n_R(w)}, YU_{n_R(w)})$ respectively, then $\mathbf{E}U_{n_L(w)} = (XU_{n_L(w)}, YU_{n_L(w)}, 1)$ and $\mathbf{E}U_{n_R(w)}^T = (XU_{n_R(w)}, YU_{n_R(w)}, 1)^T$. The value of the basic matrix $\mathbf{F}$ is:

$$\mathbf{F} = \begin{pmatrix} 3.51600012 \cdot e^{-8} & 2.03383211 \cdot e^{-8} & -0.0007490343 \\ 9.13071845 \cdot e^{-8} & -4.00114846 \cdot e^{-8} & 0.0024372422 \\ 0.00052039 & 0.00241858 & 0.1386759389 \end{pmatrix} \quad (5)$$

The matched points are reconstructed according to the internal and external parameters of the dimensional measurement system. The internal parameters of the left camera and right camera are expressed as $\mathbf{K}_L$ and $\mathbf{K}_R$, respectively. The values of $\mathbf{K}_L$ and $\mathbf{K}_R$ are:

$$\mathbf{K}_L = \begin{pmatrix} 5021.520848 & 0.000000 & 911.091634 \\ 0.000000 & 5009.472475 & 900.755903 \\ 0.000000 & 0.000000 & 1.000000 \end{pmatrix} \quad (6)$$

$$\mathbf{K}_R = \begin{pmatrix} 4888.653507 & 0.000000 & 1176.738084 \\ 0.000000 & 4854.689420 & 857.696987 \\ 0.000000 & 0.000000 & 1.000000 \end{pmatrix} \quad (7)$$

The rotation matrix of the left camera and the right camera are represented by $\mathbf{R}_L$ and $\mathbf{R}_R$, respectively. The translation vector of the left camera and the right camera are represented by $\mathbf{T}_L$, $\mathbf{T}_R$, respectively. The values of $\mathbf{R}_L$, $\mathbf{R}_R$, $\mathbf{T}_L$ and $\mathbf{T}_R$ are:

$$\mathbf{R}_L = \begin{pmatrix} -0.023014 & 0.904843 & 0.425123 \\ 0.994948 & 0.062296 & -0.078730 \\ -0.097722 & 0.421163 & -0.901705 \end{pmatrix} \quad (8)$$

$$\mathbf{R}_R = \begin{pmatrix} -0.009672 & 0.967942 & 0.250987 \\ 0.998688 & 0.021971 & -0.046249 \\ -0.050281 & 0.250210 & -0.966885 \end{pmatrix} \quad (9)$$

$$\mathbf{T}_L = \begin{pmatrix} -546.226788 \\ 307.981605 \\ 7772.801384 \end{pmatrix} \quad (10)$$

$$\mathbf{T}_R = \begin{pmatrix} -835.596397 \\ 356.480755 \\ 7709.146105 \end{pmatrix} \quad (11)$$

The matched sub-pixel edges are reconstruction according to the storage order of the 2D points. The 3D points obtained after 3D reconstruction of sub-pixel edges are shown in Fig.9. The 3D coordinate system in Fig.9 is represented by $O_{3D}X_{3D}Y_{3D}Z_{3D}$, and the unit of the coordinate axis is millimeter.

Fig.9 The three-dimensional points

5 Length calculation of hot forging

The 3D points reconstructed from the upper and lower sub-pixel edges of each light strips are employed for plane fitting, respectively. Then, the 2D points can be obtained by projecting the 3D points corresponding to the upper and lower sub-pixel edge of each light strip on its fitted plane. The 2D points corresponding to the upper edge of the light strip $n(w)$ are shown in Fig.10. In Fig.10, the coordinate system in the fitted plane is represented by $O_{2D}X_{2D}Y_{2D}$ and the unit of coordinate axis is millimeter. The 2D points in Fig.10 are represented by (x_r, y_r) , and the storage order of 2D points is consistent with the storage order of 3D points obtained from the upper edge of $n(w)$. Where, $w = 3$, $t \in [1, N_{u\_n(w)}]$, $N_{u\_n(w)}$ is the number of the 2D points.

Fig.10 The 2D points corresponding to the upper edge of the light strip $n(3)$

The curve can be obtained by fitting N consecutive 2D points taken in sequence with quintic polynomial. The expression of quintic polynomial is:

$$y_r = a_1 x_r^5 + a_2 x_r^4 + a_3 x_r^3 + a_4 x_r^2 + a_5 x_r + a_6 \quad (12)$$

Where, a_1 、 a_2 、 a_3 、 a_4 、 a_5 and a_6 are the parameter needed to be calculated, $r \in [1, N]$, $N=150$ in this paper.

The curvature ε_r of each 2D point is calculated according to the storage order by using the fitted curve and compared with the preset threshold ζ . If the curvature ε_r is greater than the preset threshold ζ , the calculation will be stopped. The curvature calculation formula is:

$$\varepsilon_r = \frac{|y_r''|}{(1 + y_r'^2)^{\frac{3}{2}}} \quad (13)$$

If the curvature value of each point is less than the preset threshold ζ , make $r \in [k \cdot N + 1, (k+1) \cdot N]$ repeat the above calculation process until the curvature value ε_r is greater than the preset threshold ζ . Where, $k=1, 2, L$, $(k+1) \cdot N \leq N_{u-n(w)}$ and $\zeta = 0.0022$.

The time required for the dimensional measurement system to measure the length of is 6.8s. The length of hot forging where the edge of light strip located is shown in Table 1.

Table 1 The length of hot forging where the edge of the light strip located

Light strip number	$n(1)$		$n(2)$		$n(3)$		$n(4)$		$n(5)$	
	Upper edge	Lower edge	Upper edge	Lower edge	Upper edge	Lower edge	Upper edge	Lower edge	Upper edge	Lower edge
Length(mm)	1883.1	1883.7	1906.8	1907.2	1933.3	1934.7	1929.3	1928.7	1988.7	1989.2

The length of workpiece at room temperature is measured by using the dimension measurement system of hot large forging. The experimental results show that the measurement error can reach 0.547%.

6 Conclusions

In order to realize non-contact length measurement of hot forgings, a length measurement method is proposed in this paper. Firstly, the transverse light strips on the surface of hot forging projected by projector are recognized by the characteristic of continuous of light strips in the image of hot forging. Secondly, the sub-pixel edge points of each light strip are calculated by an improved algorithm and employed for three-dimensional reconstruction. Lastly, the two-dimensional point set acquired by projecting the three-dimensional point set of each edge of the light strip on its fitted plane are used for curve fitting, and the edge of each light strip on the forging can be obtained by judging the curvature of the fitted curve. The distance between the starting point and the edge point in each two-dimensional point set is the length of the forging at the light strip edge. The length measurement experiment shows that this method can be used to calculate the length of hot large forgings. The measurement error of the length measurement system is 0.547% when measuring the workpiece at room temperature. The time required for the data processing system to process the collected image data and obtain the length of hot forging is 6.8s.

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Code availability Not applicable.

Declarations

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