Optical dynamic measurement of welding deformation

Gaofeng Wang,1 Fengping Yang,1 Liang Zhang,1 Yingtao Yuan2*, Xin Su2 and Xiang Guo2

1 CNPC Tubular Goods Research Institute, Xi’an, Shaanxi, 710077, China
2 School of Aeronautics, Northwestern Polytechnical University, Xi’an, Shaanxi, 710072, China
*Corresponding author’s e-mail: yuanyingtao@mail.nwpu.edu.cn

Abstract. This paper presents an optical measurement method of welding deformation. Through the use of target detection, camera calibration, 3D metric reconstruction, we obtain the precision 3D location of targets, which are deformed in welding processing. With the data, the deformation of the workpiece in welding processing can be performed, and the manufacture and design level of welding can be improved.

1. Introduction
Welding is widely used in shipbuilding, aerospace and automotive industries to assemble various products. However, the welding process relies on an intensely localized heat input, which tends to generate undesired residual stresses and deformations in welded structures, especially in thin plates. The welding distortions typically lead to uncertainty in design and manufacture and high rectification costs[1]. Therefore, measuring the magnitude of welding deformations and characterizing the effects of the welding conditions are deemed necessary.

The conventional measurement as displacement sensor measurement would be influenced by electromagnetic interference or thermal disturbance and can only measure one-dimensional deformation. However, compared with traditional measurement, optical measurement can obtain precise 3D deformation without affected by interference. This paper presents one dynamic visual size using two cameras with camera calibration[2], image processing, and 3D metric reconstruction to realize dynamic deformation measurement in the welding process.

2. Optical dynamic measurement
Optical dynamic measurement presented in this paper include target detection to obtain the location of deformation in each image; camera calibration to eliminate the distortion and get the relationship of cameras; 3D reconstruction to calculate 3D metric of targets by each pair of doubles.

Figure 1. Circle target pattern.
This paper uses the circle targets[3] to perform the deformation of welding, as Figure 1 shows. First, use the canny algorithm to detect the edge[4], extract sub-pixel edge using mean gradient algorithm, finally fit ellipse centre to obtain ellipse parameters (the centre location, long axis a, short-axis b, angle contained by long axis and short axis). This paper, using a gradient-based sub-block detection algorithm to increase efficiency. The result is shown in Figure 2.

Figure 2. Result of targets centre location and code.

For digital camera photography, camera lens distortion and imaging plane distortion are the main factors to interfere with imaging[5]. Moreover, the error of inner orientation elements will disturb the establishment of the collinearity equation. Taking into account the mistakes of imaging, establish a collinearity equation:

\[
\begin{align*}
\Delta x' &= -f \frac{a_1(x_w - x_0) + b_1(y_w - y_0) + c_1(z_w - z_0)}{a_2(x_w - x_0) + b_2(y_w - y_0) + c_2(z_w - z_0)} \\
\Delta y' &= -f \frac{a_3(x_w - x_0) + b_3(y_w - y_0) + c_3(z_w - z_0)}{a_4(x_w - x_0) + b_4(y_w - y_0) + c_4(z_w - z_0)}
\end{align*}
\] (1)

Using ten parameters distortion model, make equation (1) linear, obtain:

\[
V = AX_1 + BX_2 + CX_3 - L
\] (2)

Where \(V\) is the residuals of image point; \(X_1\) is inner orientation elements (including distortions); \(X_2\) is extrinsic parameters; \(X_3\) is the correction of object-point coordinates. \(A\), \(B\) and \(C\) are their corresponding partial derivative matrix. \(L\) is the observed value.

Figure 3. Camera calibration board.
As Figure 3 shows, a camera calibration board is utilized to record the several pairs of images recording by both cameras. Calculate the center pixel position of targets. Equation (2) is utilized to obtain the inner orientation elements and extrinsic parameters.

3D metric reconstruction includes two parts, target-matching and 3D metric calculation. For coded targets, targets are matched by their code. For uncoded targets, targets are matched by epipolar constraint in this paper. After target-matching, using two cameras' inner orientation elements and extrinsic parameters and matched points to calculate the 3D metric[6]. Set the projection matrix of two cameras as 

\[
\begin{bmatrix}
L L \\
R R \\
L L \\
R R
\end{bmatrix} = A_L [R_L | t_L] \quad \text{and} \quad \begin{bmatrix}
L L \\
R R \\
L L \\
R R
\end{bmatrix} = A_R [R_R | t_R], \quad \text{location in images is} \ (u_L, v_L) \quad \text{and} \quad (u_R, v_R).
\]

The 3D metric of point can be calculated by least-squares algorithm, as equation (3) show:

\[
W = (AA^T * AA)^{-1} * AA^T * BB \tag{3}
\]

Figure 4. Result of 3D metric reconstruction.

As Figure 4 shows, the bottom is the Left and Right Camera; the above is the 3D Metric of targets. After the 3D Metric of targets calculated, match the points between each stage. For coded targets, match by their code. For uncoded targets, search the nearest and less than given threshold point to match each point. Then calculate the location deviation of each matched point.
3. Welding deformation experiment

Use optical dynamic measurement presented by this paper to measure the deformation of stainless steel welding. As Figure 6 shows, the hardware of the measurement system includes two cameras, two LED lights and Fixtures. Figure 7 and Figure 8 shows the process of measurement. For comparison, set three displacement Sensors at Point 1, 2 and 3 as Figure 7 shows.

![Figure 5. The flowchart of the data processing.](image)

![Figure 6. Hardware and software of measurement system.](image)
Figure 7. Welding experiment of stainless steel.

Figure 8. Welding process.

Figure 9. Comparison of displacement sensor 1st.
Figure 9, Figure 10 and Figure 11 show that the results of optical dynamic measurement and displacement sensors are similar. The result of the displacement sensor is smaller because that first, the location of displacement sensors cannot be diametrically perpendicular to the stainless steel, especially when the steel deformed; the second result of displacement sensors performed only one dimension of deformation, an optical dynamic measurement performed deformation in 3D metric.
Comparison with conventional means of measurements, optical dynamic measurement can be placed in any location, not be interference by an electromagnetic, much more comprehensive range of size and obtain the 3D metric deformation precisely in a reasonable time. As Figure 12 shows, the deformation around the weld seam can be performed by optical dynamic measurement; conventional measurement as displacement sensor cannot be placed in this area. As Figure 13 shows, using appropriate methods, the displacement field can be obtained.

Figure 13. Displacement field of welding deformation, (a) is the stage just after the welded; (b) is stage 4mins after the welded.

4. Conclusion
According to results obtained in the present work, the conclusions can be summarized as follows:

1) Optical dynamic measurement can obtain real-time 3D metric deformation of welding without interference by electromagnetic.

2) Optical dynamic measurement is a non-contact measurement method that can be used in many fields such as welding manufacture, monitor, estimate and experiment.

3) Optical dynamic measurement can improve the efficiency and precision of welding deformation measurement and the manufacture and design level of welding.
Acknowledgments
This work was supported by grants from the National Natural Science Foundation of China (Nos. 12072279, 11372256, 11527803, 11602201, 11502216, and 11602202) and Natural Science Basic Research Plan in Shaanxi Province of China (No. 2018JQ1060).

References
[1] Wang, R., Zhang, J.X., Serizawa, H. and Murakawa, H. (2009) Study of welding inherent deformations in thin plates based on finite element analysis using interactive substructure method. Mater. Design, 30, 9: 3474-3481.
[2] Zhang, Z.Y. (2000) A flexible new technique for camera calibration. IEEE T. Pattern. Anal, 22, 11: 1330-1334.
[3] Xiao, Z.Z., Liang, J., Yu, D.H., Tang, Z.Z. and Asundi, A. (2010) An accurate stereo vision system using cross-shaped target self-calibration method based on photogrammetry. Opt. Laser. Eng, 48,12: 1252-1261.
[4] Canny, J. (1986) A computational approach to edge detection. IEEE T. Pattern. Anal, 6: 679-698.
[5] Fraser, C.S. (2001) Photogrammetric camera component calibration: A review of analytical techniques. In: Workshop on Calibration and Orientation of cameras in Computer Vision. Washington, DC. 95-121.
[6] Tang, Z. (2008) Research and Implement on Key Technology of Digital Close-Range Photogrammetry. Xi'an Jiaotong University, Xi'an.