Journal of University of Science and Technology Beijing
Volume 11, Number 2, April 2004, Page 178

Materials

Deforming analysis of sheet metal based on stereo vision and coordinate grid

Hongqin Wei[1], Dehong Yu[2], Xueyu Ruan[1], and Youqing Wang[1]

1) Department of Plasticity Technology, Shanghai Jiaotong University, Shanghai 200030, China
2) Die or Mould and Plasticity Processing Research Institute, Xi'an Jiaotong University, Xi'an 710049, China
(Received 2003-04-06)

Abstract: A new approach based on stereo vision technology is introduced to analyze sheet metal deformation. By measuring the deformed circle grids that are printed on the sheet surface before forming, the strain distribution of the workpiece is obtained. The measurement and analysis results can be used to verify numerical simulation results and guide production. To get good accuracy, some new techniques are employed: camera calibration based on genetic algorithm, feature abstraction based on self-adaptive technology, image matching based on structure feature and camera modeling pre-constrains, and parameter calculation based on curve and surface optimization. The experimental values show that the approach proposed is rational and practical, which can provide better measurement accuracy with less time than the conventional method.

Key words: sheet metal forming; deforming analysis; stereo vision, coordinate grid

Sheet metal forming mechanism is very complicated for its nonlinear properties. In recent years considerable progress has been made in numerical simulation to investigate the sheet forming process. But physical modeling techniques develop comparatively slowly and there are no enough and valid experiment data to verify the simulation results. The coordinate grid analysis method has been a very useful tool for sheet forming engineers in the past. In this method, the deformed grids printed on the workpiece surface are compared with their original dimensions, which can help checking the process security, finding die defects, monitoring and controlling the production [1]. But the conventional manual measurement of grids need long time and the accuracy is low and unsteady.

Some researches have been done in the automatic measurement of strains for square grids [2, 3], but there are still no reports on circle coordinate grids which is applied more extensively in practical production. Meanwhile, owing to large quantity and small size of grids, the measurement accuracy is unsatisfying. In this paper, a new method based on computer vision, which aims at high accuracy and speed, is presented to obtain the sheet metal strain distribution for circle grids.

1 Measurement and analysis principle of sheet metal strain

1.1 Three-dimensional measurement of stereo vision

Stereo vision obtains the 3D information of an object from two views as schematically shown in **figure 1**. Point P has two images P_1 and P_2 respectively on camera C_1 and C_2 (O_1 and O_2 are the camera optical centers, while I_1 and I_2 are image planes). According to the imaging geometry principle, P is on line O_1P_1 and O_2P_2 at the same time. Therefore P is the intersection point of two lines, and its position can be determined exactly by the image coordinates of P_1 and P_2.

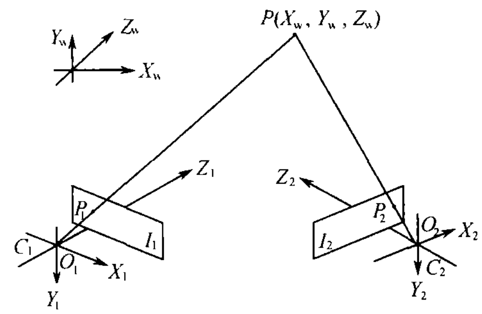

Figure 1 Stereo vision imaging geometry graph.

The projection relation between $P(X_w, Y_w, Z_w)$ and its image (u, v) (unit: pixel) can be shown as [4]:

$$Z_c\begin{pmatrix}u\\v\\1\end{pmatrix}=\begin{bmatrix}m_{11}&m_{12}&m_{13}&m_{14}\\m_{21}&m_{22}&m_{23}&m_{24}\\m_{31}&m_{32}&m_{33}&m_{34}\end{bmatrix}\begin{pmatrix}X_w\\Y_w\\Z_w\\1\end{pmatrix}=\boldsymbol{M}\boldsymbol{X}_w^{'} \quad (1)$$

where $\boldsymbol{M}$ is defined as a projection matrix and can be gotten from camera calibration. Z_c is the Z coordinate of P in the camera coordinate system (CCS). According to this formula six equations containing (X_w, Y_w, Z_w) are derived to compute the spatial coordinates of P

Corresponding author: Hongqin Wei, **E-mail:** hqwei@sjtu.edu.cn

with least square algorithm.

1.2 System working principle

The devices employed for strain measurement are shown in **figure 2**. They are a CCD camera, an image card, a personal computer, a monitor and a positioning platform. A workpiece can be moved on the positioning platform in three directions perpendicular to each other. The measurement principle diagram is schematically shown as **figure 3**. Firstly, grab two images of the workpiece in different directions, then abstract the image features respectively, which contains as follows:

(1) Image enhancement. That is to improve the image quality by decreasing noise and equalize gray level distribution;

(2) Image thresholding. Turning the original photos into binary images;

(3) Contour extraction. Tracking the binary images to get an image contour with single-pixel-width;

(4) Feature recognition. Separating the grid circle contour from contour images.

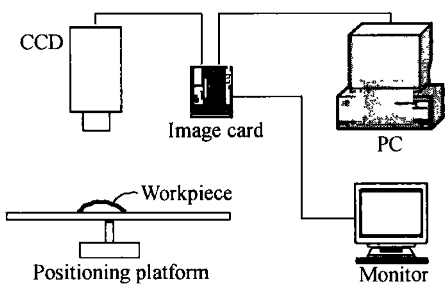

Figure 2 Measurement devices.

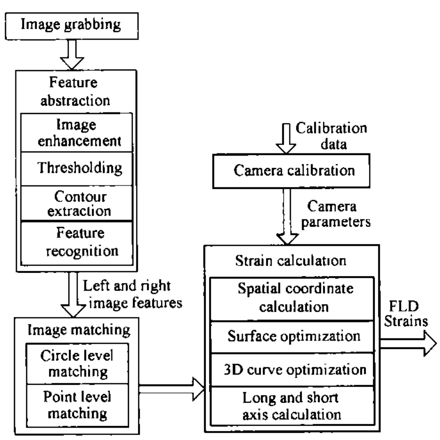

Figure 3 Measurement principle diagram.

Thirdly, match the features of two images, which is implemented by two steps: circle level matching and point level matching. Finally, compute the spatial coordinates of feature points based on camera parameter calibration results, from which circles' geometry parameters and strains are carried out to get the strain distribution on the surface. All these are integrated in the sheet metal deformation measurement software system.

2 Key technologies

2.1 Camera calibration based on genetic algorithm

Two images are captured by one camera here. To facilitate stereo matching, the workpiece is moved along the X axis of the location platform, which is selected as World Coordinate System (WCS) and the X axis of Image Coordinate System (ICS) [4] is adjusted parallel to WCS'.

Camera calibration aims at obtaining the projection relation between the spatial point and its image, that is to say, getting camera's external and internal parameters. A panel with square grids is selected as the calibration reference object and the intersection points of grids are feature points, as shown in **figure 4**. The panel can be placed on different heights, hence there are enough data to guarantee the computation precision of the projection matrix. Conventional calibration is based on linear assumption, but because of lens aberrance, the relation is nonlinear [5]. To build the true projection relation, a new method based on genetic algorithm is employed. Firstly camera parameters are estimated by the least square algorithm, then the estimated parameters are used as initial values, and based on the calibration points data, camera parameters are optimized by genetic algorithm. By this method the camera calibration accuracy is improved greatly.

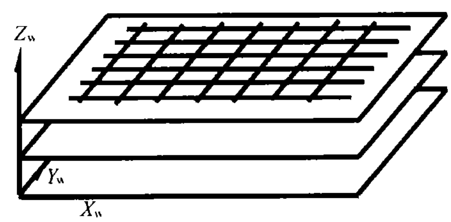

Figure 4 Calibration reference object.

2.2 Extraction and description of circle grid feature

The original image has noise and uneven gray level distribution, so it is necessary to improve the image before abstracting features. Some filter algorithms are applied. Then enhanced images are turned into binary images by dynamic self-adaptation thresholding method. The circle grid contour is gotten through edge searching and tracking of binary image frames, the process is as follows:

(1) Giving the search region;

(2) Scanning and searching the start point of the edge;

(3) Tracing the contour and labeling it until the contour closed or reaching the image boundary;

(4) Saving the contour path in a file;

(5) Beginning a new search from the height of the last contour's start point until the whole region has been scanned.

Three kinds of contour paths are obtained: closed (circle and clearance), unclosed (image edge) and scattered spot. The last two should be discarded. The unclosed contour can be excluded by the definition of closed path, while the scattered spots by their contour length. The contour image has clear structure, in which grids and clearances are distributed alternately and regularly to form an array, which can be described as a matrix. Every matrix element corresponds to a single-union region. By excluding clearance elements, the final contour matrix containing only circle grids can be gained, as schematically shown in **figure 5**.

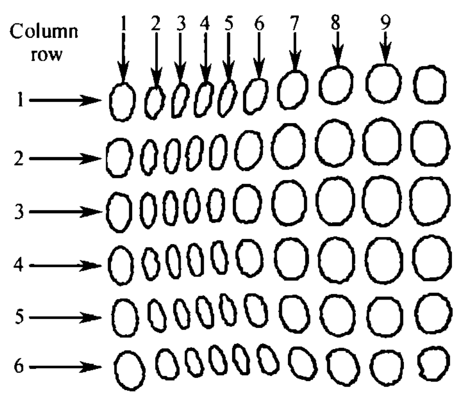

Figure 5 Matrix description of circle grids.

2.3 Stereo matching based on the structure feature of image and camera pre-constrains

Matching is the most difficult problem in stereo vision and until now there is no mature solution [6]. In this paper, a method based on image structure feature and camera model pre-constrain is proposed to establish the exact correspondence between left and right image feature points quickly, which contains two steps:

(1) Circle level matching. As the results of feature abstraction, two contour matrix describing circle elements can be gotten respectively from left and right images. If we keep the coding orders of two images same to each other by the real corresponding relation of circles, two elements at the same place in the two matrix represent the two corresponding circles and matching is implemented. To make circles' coding order same, a pair of circles needs to be pointed manually, then other circles are matched according to the position parameters (such as circle center coordinates).

(2) Point level matching. The WCS' X axis is adjusted to be horizontal and the camera is located to ensure that ICS' X axis is parallel to WCS' X axis (see section 2.1), therefore the two images of a point have the same vertical coordinate on the image panel, by which the point matching can be realized. As shown in **figure 6**, the circle is broken into two parts by the highest and lowest points, which can be called left link and right link, and the two links of left circle correspond to two links of right circle respectively.

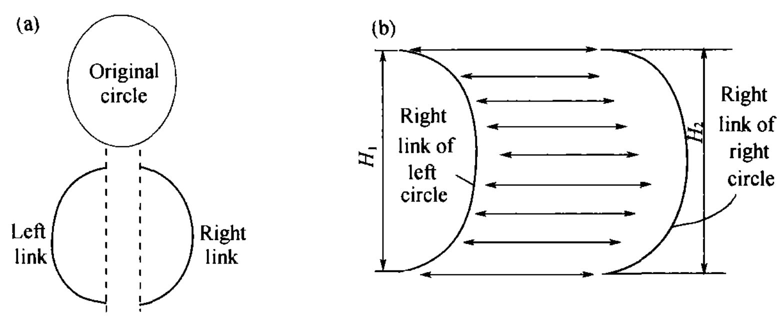

Figure 6 Point matching: (a) left and right links of circle; (b) correspondance of links.

2.4 Calculation and analysis of sheet metal deforming parameters

For one circle on the sheet surface, a pixel pair sequence of contour and center points can be gotten. Their spatial coordinates are calculated according to formula (1). In sheet forming, the major and minor axes of the circle indicate the directions of maximum and minimum strains. Assuming that d_0 is the original circle diameter, while d_1 and d_2 are respectively the major and minor axis length of the deformed circle, the local principal strains can be computed as follows:

$$\begin{aligned} \varepsilon_1 &= \ln(d_1/d_0) \\ \varepsilon_2 &= \ln(d_2/d_0) \end{aligned} \quad (2)$$

The real sheet surface and grid circle are smooth, so in order to get good accuracy, the surface and curve are optimized from contour points to decrease the error caused by former processing [7]. Then the real grid parameters of d_1 and d_2 are calculated. From the strain obtained by formula (2), the workpiece's strain distribution and Forming Limit Diagrams (FLD) can be gotten to analyze the production process and material formability. In case that FLD is known, comparing strains with FLD can indicate the forming crisis area and guide practical production.

3 Analysis of experimental results

Based on the technologies presented above, a series of tests were conducted. **Figure** 7(a) is the original images of a workpiece. The original circle diameter is 2 mm. The threshold results and contour images are shown in figures 7(b) and (c). Because of the symmetric structure, only half of the workpiece is analyzed. **Figure 8** is the major and minor axes strain distributions. For the same workpiece, measurement is also carefully done by optical microscope. The error between the results respectively from stereo vision and microscope is illustrated in **figure 9** (nine circles in the third row of the image are analyzed). The figure shows that two kinds of results conform to each other well. The error is within 5%. With camera parameters given, a complete measurement of the workpiece similar to figure 7 costs less than 2 min. Relative to manual measurement, the accuracy has been promoted greatly. Using CCD camera and image card with higher resolution can increase the strain accuracy further.

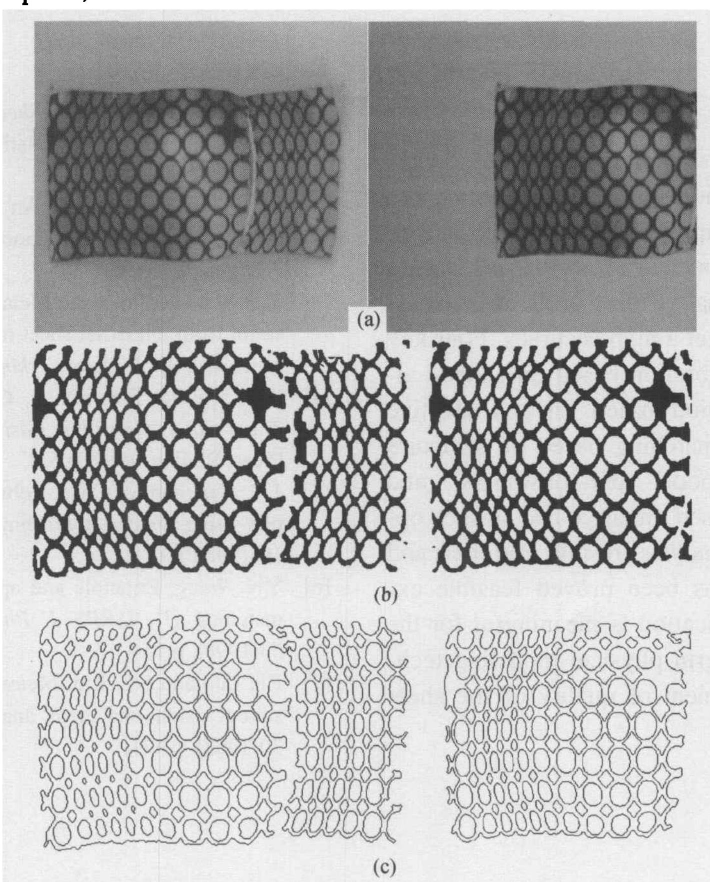

Figure 7 Feature abstraction: (a) original images; (b) binary images; (c) contour tracking.

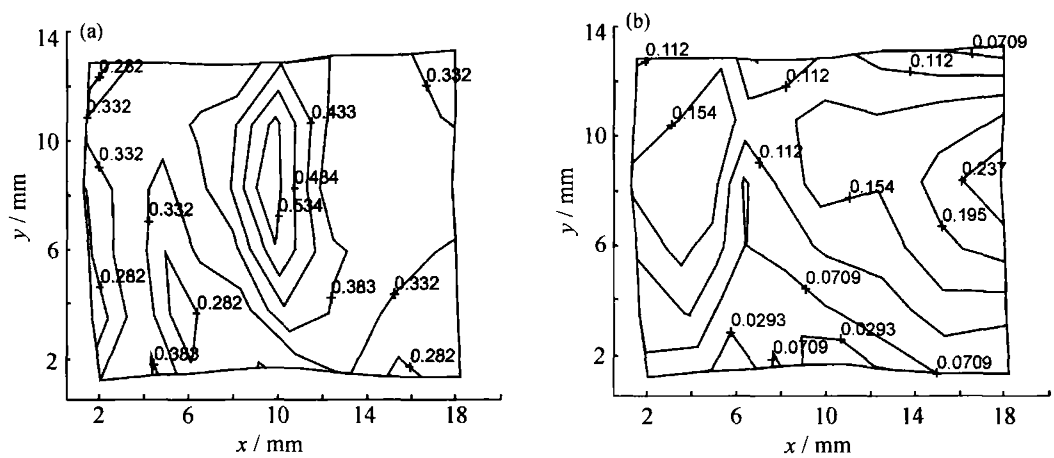

Figure 8 Strain distributions: (a) major strains; (b) minor strains.

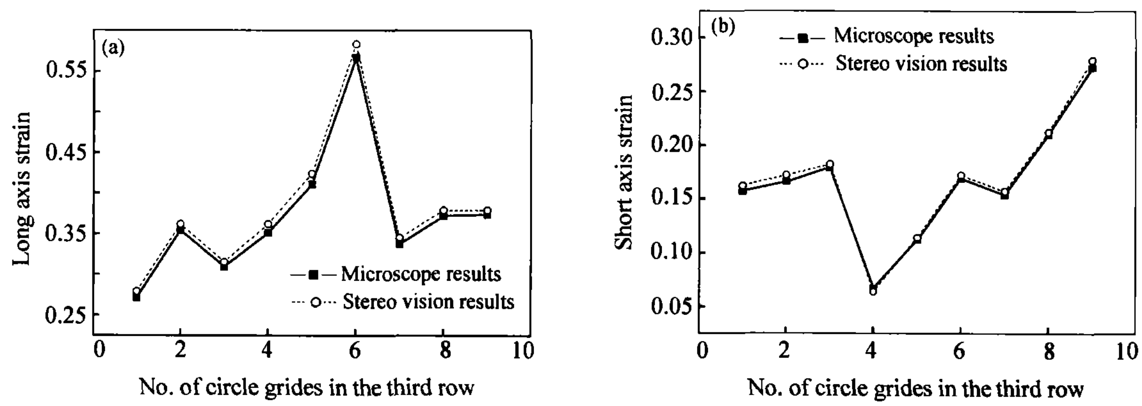

Figure 9 Comparison between strain values from stereo vision and optical microscope: (a) major strains; (b) minor strains.

4 Conclusions

The sheet forming physical modeling based on coordinate grids can provide strain distributions and guide production. The application of stereo vision technology makes the work easier and faster. Due to the large quantity and small size of grids, it is necessary but also difficult to get a high accuracy. Four key technologies: camera calibration based on genetic algorithm, feature abstraction based on self-adaptive technique, exact image matching based on structure feature and camera model pre-constraints, and parameters calculation based on curve and surface optimization, make the analysis results rational and practical. The method has been proved feasible experimentally, whose application is meaningful for the extension of coordinate grid physical modeling technology and the improvement of quality of the sheet forming workpiece.

References

[1] S.G. Hu and Z.H. Chen, *Sheet Metal Cold Stamping Principle* (in Chinese) [M], National Defense Industry Press, Beijing, 1989, p.257.

[2] J.H. Vogel and D. Lee, An automated two-view method for material shaping technology [J], *J. Mater. Shaping Technol.*, 6(1989), p.205.

[3] Erik Schedin and Arne Melander, The evaluation of large strain from industrial sheet metal stampings with a square grid [J], *J. Appl. Metalworking*, 4(1986), p.143.

[4] S.D. Ma and Z.Y. Zhang, *Computer Vision—Computing Theory and Algorithm Basis* (in Chinese) [M], Science Press, Beijing, 1997, p.52.

[5] J.X. Chai and S.D. Ma, Robust epipolar geometry estimation using genetic algorithm [J], *Pattern Recognit. Lett.*, 19(1998), p.828.

[6] Y.N. Wang, Principle and application of structural image matching [J], *ISRPS J. Photogramm. Romote Sensing*, 53(1998), p.154.

[7] P.F. Luo and S.S. Liu, Measurement of curved surface by stereo vision and error analysis [J], *Opt. Lasers Eng.*, 30(1998), p.471.