CHEMICAL ENGINEERING TRANSACTIONS

VOL. 66, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216

DOI: 10.3303/CET1866154

Application of Digital Image Technology in Material Mechanics Property Test

Zhuo Jin[ab], Chunggun Jang[c], Yonghua Yi[d*]

[a]Bozhou University, BoZhou 236800, China;
[b]Marine Convergence Design, Pukyong National University, Pusan 48513, Korea
[c]Dept.of Visual Design,Pukyong National University, Pusan 48513, Korea
[d]College of Economics and International Trade, Pusan National University, Pusan 46241, Korea
*yyh08091@gmail.com

Apply digital image technology in material mechanics property test and research and analyze the application process and structure. At material tensile stage, improve previous calibration and matching method based on traditional stereoscopic measurement, improve the accuracy and timeliness of several calibration points, change the factor and accelerate the matching speed combining small included angle to timely and accurately rebuild three-dimensional topography of deformed surface. Beside, measure the displacement field and strain field by using the unilateral camera. Finally obtain the curves of maximum tensile strain and tensile strain rate of strain point VS time. Application of digital image technology in material mechanics property test is key technology to guarantee the accuracy of test result, so it has certain promotion and application value.

1. Introduction

Under rapid industrial development, new materials constantly emerge and functions of materials is also becoming more and more perfect. Under such environment, material mechanics property test has been applied importantly. With continuous development of modern technology, information technology, communication technology and computer technology covers more fields. Digital image is a new technology fusing information and computer technology and other modern advanced technologies and a non-contact full-field optical measurement method applied more in various industries recently, and thanks to easy operation, good application result, fast search speed and accurate fixed point, it is widely applied to measurement of many fields, including material mechanics property test. Digital image measurement method was mainly used for displacement measurement of rigid body in initial development period, and under rapid development of modern technologies, application of digital image technology is unceasingly expanding and measurement level is also increasingly improved. Digital image technology has fully developed at home and abroad, and present measurement data show that three-dimensional speckle measurement method is more applicable to plane displacement measurement. Three-dimensional image method can cover the shortages of two-dimensional speckle measurement method and carry out the out-plane displacement measurement. Research on three-dimensional image method still stays at the initial stage and there are less cases of practical engineering application, so the relevant methods of digital image technology should be further improved.

2. Literature review

Since the 1980s, Professors Peters and Ranson of the University of South Carolina have been leading the way in the study of digital image correlation methods. They made outstanding contributions to the theoretical improvement and development of digital image related methods. Initially, Professors Peters and Ranson used television cameras to record speckle patterns before and after deformation of the surface of the object. Then, the iterative computation of the gray field after digitalization is carried out. The position of extreme points of correlation coefficient is obtained by numerical calculation, and the corresponding displacement and gradient are obtained. From then on, finding the correlation operation of the correlation coefficient extreme point position becomes one of the core problems in the digital image correlation method.

Please cite this article as: Jin Z., Jang C., Yi Y., 2018, Application of digital image technology in material mechanics property test, Chemical Engineering Transactions, 66, 919-924 DOI:10.3303/CET1866154

In recent years, with the rapid development and widespread application of intelligent optimization algorithms, many researchers at home and abroad have applied some new intelligent optimization algorithms to digital image correlation calculations. García et al. combined a non-integral pixel transformation model established by Sjödahl et al. and an artificial neural network algorithm to propose a sub-pixel search algorithm based on neural networks (García et al., 2014). Since the algorithm does not need to know the specific analytical form of the correlation function and can obtain global displacement after one training, the solution speed is very fast. In the same year, Awada and Nathanson et al. proposed an intelligent digital image correlation method using genetic algorithms to solve the global displacement and strain (Awada and Nathanson, 2015). Shu et al. proposed a point-by-point digital image correlation method based on genetic algorithms (Shu et al., 2015). Tymrak et al. combined a quasi-Newton method with a genetic algorithm to propose a hybrid algorithm (Tymrak et al., 2014).

The measurement accuracy of the digital image correlation method has always been a hot issue. It is not only affected by the related search algorithm, but also affected by various other factors such as various noise, speckle particle size, image subset size, interpolation methods and son on. Researchers have done a lot of research around accuracy impact factors and noise reduction methods. Veleva et al. conducted in-depth theoretical analysis of the three major precision influencing factors of digitization of the speckle pattern, sampling frequency, and sub-pixel interpolation method, which provided a theoretical basis for further improvement of calculation accuracy (Veleva et al., 2015). From 2001 to 2002, Jin Guanchang et al. conducted a more in-depth study on applying wavelet method to reduce noise. They have achieved good results. Jiang analyzed the influence of the size of the speckle particles on the accuracy of digital image correlation measurement. The results of the study show that the pixels are optimal when the speckle size is 2-5. At the same time, he also proposed a digital simulation speckle algorithm. It provides the basis for quantitative evaluation, verification, and comparison of digital image correlation algorithms (Jiang et al., 2014). Gong analyzed the effect of the size of the image subset on the measurement accuracy. He found that the optimal size of the image subset is 41×41-61×61 pixels (Gong et al., 2015). In order to improve the measurement accuracy of the surface displacement of objects with large-angle rigid bodies, Wang Jing and Li Hongqi proposed a digital image correlation method based on circular subsets. Meng Libo analyzes in detail the effects of interpolation methods and displacement modes on measurement accuracy. In 2007, Wang Zhiyong and Pan Bing established a theoretical model of displacement measurement accuracy based on one-dimensional and two-dimensional correlation functions, respectively. It lays a theoretical foundation for the quality evaluation of speckle images and the selection of image subset size. Wang Zhiyong et al. further studied the speckle size and established the relationship between the speckle size and the grayscale gradient of the speckle pattern. In addition, the measurement accuracy of the digital image correlation method is also affected by the layout of the measurement system and the hardware conditions. In order to reduce the in-plane displacement measurement error caused by the out-of-plane displacement of the measurement system, the literature points out that a telephoto lens should be used in the digital image correlation measurement system. When the optical path is arranged, the optical axis of the camera should be perpendicular to the surface of the measured object, but the absolute vertical relationship between the two cannot be guaranteed in practice. For this reason, the literature analyzes and studies in detail the errors caused by the non-perpendicularity between the optical axis of the camera and the object surface in the digital image correlation. The results of the study showed that when the deviation of the normal axis of the CCD camera from the measured surface normal is less than 5°, the measurement error (theoretical value < 0.005 pixels) is small, which can be ignored. Through the method of cross grid plate calibration, the camera lens distortion correction coefficient is obtained, and the displacement measured by the digital image correlation method is corrected. To a certain extent, the measurement accuracy is improved (Carozzi and Poggi, 2015). Aiming at the measurement of micro-displacement under scanning electron microscope, an effective lens distortion correction method is proposed. It improves the accuracy of displacement and deformation measurements at the micro and nano scales.

In summary, in the modern optical metrology technology, the digital image correlation method has become a simple, practical and effective quantitative measurement method of displacement and strain in the whole field. This method has been widely used in experimental mechanics and other scientific research fields due to its advantages such as simple optical path, good environmental adaptability, wide measuring range, and high automation degree. However, the current digital image correlation method still has certain deficiencies in the speed of positioning the entire pixel and the accuracy of the sub-pixel solution. It needs to be further studied and improved to meet the requirements of engineering measurement. Therefore, aiming at the influence of the traditional pixel-based gray value-based correlation function and point-by-point search strategy on the whole pixel positioning speed of the digital image correlation method, an integer pixel search algorithm combined with image invariant moments and particle swarm optimization is proposed.

3. Research method

Based on relevant foreign and domestic technological theories of digital image and application research results, for the purpose of improvement of integer pixel search speed and sub-pixel solution accuracy, plan to build a new integer pixel search method by using image feature sequence and intelligent optimization algorithm and to build a sub-pixel iterative gradient algorithm by using non-linear optical flow equation and iterative least square method, and conduct the research on the performance of two algorithms. In addition, to further improve the calculation accuracy and efficiency of sub-pixel algorithm, plan to build image subset size operation and selection algorithm by using Shannon entropy of specklegram subset as the index. Finally, conduct the research on tensile experiment of material mechanics property test system based on double-camera tracking. Specific research contents are as follows: 1. to improve integer pixel search speed of relevant methods of digital image, this paper plans to build the relevant functions of specklegram reference subset and deformation subset by using image moment invariant with less parameters and carry out fast optimization solution of relevant functions based on image moment invariant by using particle swarm optimization algorithm to obtain integer pixel displacement. 2. Considering of gray change of specklegram caused by coupled effects of environment change, hardware deviation, uneven load and other factors, this paper plans to build the iterative gradient algorithm by using non-linear optical flow equation and iterative least square method to improve the algorithm adaptability to environment and other changes. 3. In relevant methods of digital image based on subset, image subset size has great effect on algorithm accuracy and efficiency. This paper plans to research the relationship between Shannon entropy of image and solution accuracy of algorithm starting with information theory, and build the image subset size operation and selection algorithm based on subset entropy by using subset entropy as the index and improve the calculation accuracy and efficiency of the algorithm. 4. conduct the research on tensile experiment of material mechanics property test system based on double-camera tracking based on the relevant theories of digital image proposed in this paper to verify the correctness of relevant theories of digital image herein and feasibility and superiority of test system applied in material mechanics property test and prove that this system can be applied to research on mechanics property test of various materials. In the calibration of binocular stereoscopic measurement, make the calibration block with several calibration points measured accurately, and images of calibration block in right and left cameras are as shown in Figure 1. Each calibration point has only image coordinates in right and left images. 4.

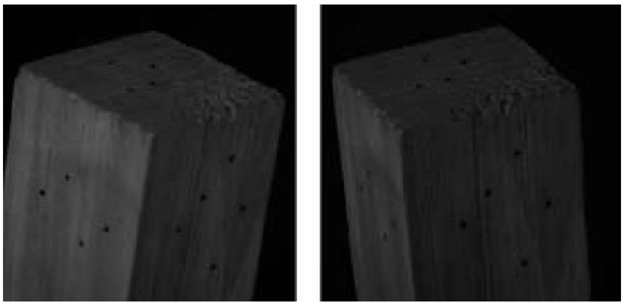

Figure 1: Image of calibration block from binocular device

4. Research result and discussion

Application of binocular stereoscopic optical measurement technology in material tensile measurement can implement two functions. The first function is rebuilding three-dimensional topography of the material at certain moment by using images taken by right and left cameras and relevant methods of digital image and three-dimension theory; the second function is obtaining deformed displacement field and strain field through calculation based on images at different moments taken by unilateral camera by relevant methods of digital image.

4.1 Three-dimensional reconstruction of surface topography during material tensile process

As shown in Figure 2, the original point in world coordinate system is defined on calibration block, each calibration point has only world coordinates, and measure the coordinates of calibration points on calibration block in world coordinate system and image coordinate system. Take the left image as an example, world coordinates and image coordinates of calibration point are as shown in Table 1.

After calibration of stereoscopic measurement system, conduct three-dimensional measurement of deformed surface of the material to complete three-dimension rebuilding, taking PC material as an example, as shown in

Figure 3, spray the random speckles in advance to used for relevant matching of digital images. Binocular stereoscopic vision measurement experimental facility is as shown in Figure 3. Adjust the angle of axes of right and left cameras of less than 30°, and use the square subarea of left image to search the relevant maximum square subarea in right image at the time of relevant matching of digital images to greatly improve the matching speed without considering that shape change factor participating in the matching. According to three-dimensional measurement theory, world coordinates of a space point can be obtained according to image coordinates and camera parameter matrix N, as shown in Formula (2), it can list 2 equations by using unilateral image coordinates and N matrix parameters and four equations according to right and left image coordinates, so that it can obtain the coordinates of any pixel of image in world coordinate system, thus realizing three-dimensional rebuilding.

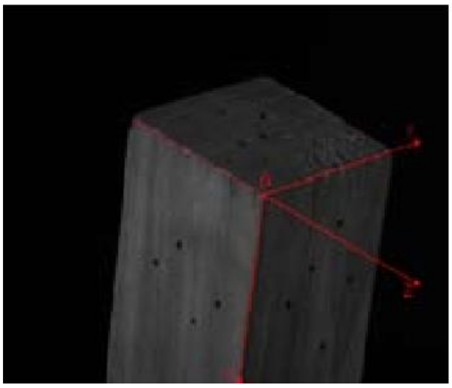

Figure 2: Establishment of unconditional reference frame

Table 1: Coordinates of world coordinates (X,Y,Z) and image coordinates (U,V)

The serial number	X/cm	Y/cm	Z/cm	U	V
1	1.00	2.00	0	959	540
2	1.50	1.50	0	881	649
3	2.00	1.00	0	812	742
4	2.00	2.50	0	990	679
5	3.00	2.00	0	909	847
6	1.50	0	-1.75	503	592
7	2.00	0	-2.25	436	847
8	2.00	0	-0.75	613	592
9	2.50	0	-1.25	544	778
10	0	1.50	-2.50	623	268
11	0	2.00	-2.00	743	280
12	0	1.00	-1.50	677	346
13	0	1.50	-1.50	738	328

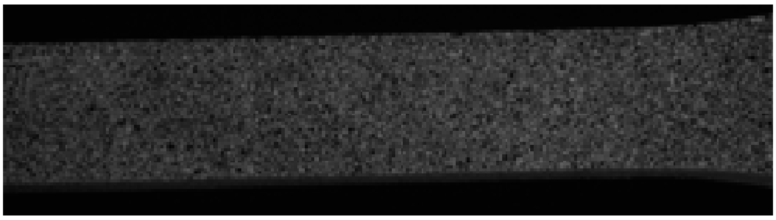

Figure 3: Image after disheveled points spouted on material surface

Through comparison of images at particular moment and initial time, calculate the displacements of each pixel in x and y directions before and after deformation based on relevant methods of digital image and obtain the displacement field u (x,y) and v (x,y) in x and y directions at certain moment. For measurement area selected in the image before deformation, the right is the image at t=248s deformation moment. Figure 4 is the displacement change of test piece u(x) of axes at t=248s.

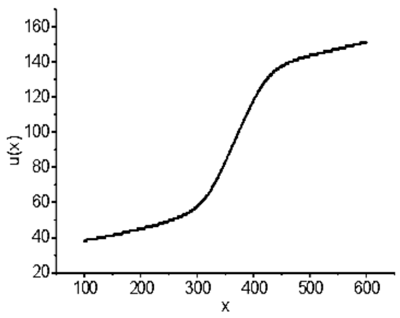

Figure 4: The u (x) of axes at t =248s

Strain field is obtained through derivation of displacement field, but displacement field is in the unit of pixel and has calculation error, and direct derivation may cause unnecessary error. Deformation of test piece in thickness direction is even at the macro level, so it can carry out curve fitting by using displacement curve of axes of wide surface of test piece in Figure 4 near possible maximum strain point, obtain the fitting curve, carry out the derivation of fitting curve, obtain the maximum value of the derivative and x coordinate, and this is the maximum engineering strain. Figure 5 shows the change rule of maximum engineering strain on test piece and Figure 6 shows the change rule of tensile strain rate of max-strain-point VS time.

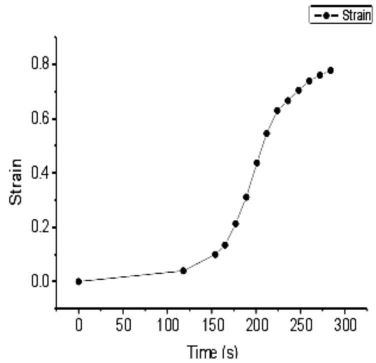

Figure 5: Max-Tension-Strain VS time

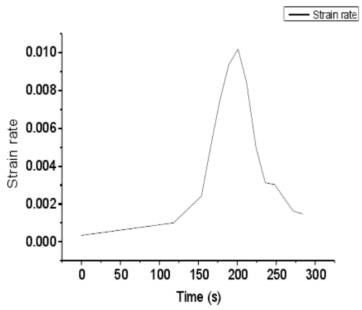

Figure 6: Strain rate of Max-Strain-Point VS time during drawing

4.2 Experimental verification of the algorithm

To eliminate the effects of accuracy of loading system, out-plane displacement, lens distortion and other factors of image acquisition system on displacement measurement results, this experiment uses the computer simulation experiment to replace real displacement measurement experiment. For the specklegram and corresponding gradation histogram of simulation experiment, the specklegram is obtained through real measurement systems of digital image in the laboratory. The system lighting uses the laser diode with wave length of 650nm and power of 5mv. The specklegram is 416×416 pixel 8-bit laser specklegram and as reference image of the experiment. To compare the sensitivity to gray change, calculation accuracy and efficiency of above algorithm, three groups of experiment are carried out in this section. Then conduct displacement measurement calculation of these 7 speckle images by using three iterative gradient algorithms and select 2601 (=51×51) even calculation points of each pair of speckle images (Distance between adjacent calculation points is 10 pixels). Reference subset size is 41×41 pixels. For the curves of average error and standard error of above algorithms VS gray change, average error and standard error of traditional iterative gradient algorithm sharply rises with increase in gray change gradient, average error and standard error of iterative gradient algorithm based on linear optical flow equation also rises with increase in gray change gradient, more slowly than traditional iterative gradient algorithm, but the curves of average error and standard error of iterative gradient algorithm based on non-linear optical flow equation always tend to be stable, which indicate that the iterative gradient algorithm based on non-linear optical flow equation is insensitive to illumination and other environment changes and has high robustness.

5. Conclusion

It is discovered that external factors are key factors affecting material tensile capacity after a series of research. To ensure the correctness and scientificity of material mechanics test data, introduce the digital image technology during the process of material mechanics property test, rebuild three dimensions of surface topography during material tensile process through binocular measurement system to clearly and intuitively the surface changes of material during tensile process, and it can refer to change data when making the scheme of improvement of material mechanics property later. Application of digital image technology in material mechanics property test covered the shortages of binocular stereoscopic measurement and calibration method, can complete relevant calibration work quickly and accurately by using several calibration points, changes the factors through shape combining narrow angle shooting situation, and highlights the material mechanics property test features. Meanwhile, amend the matching method of right and left images properly to improve the matching correctness and also improve the test efficiency. During the process of measurement of displacement and strain at material tensile stage, use iterative search means to improve the measurement speed according to continuous deformation because of tensioning.

Reference

Awada A., Nathanson D., 2015, Mechanical properties of resin-ceramic CAD/CAM restorative materials, Journal of Prosthetic Dentistry, 114(4), 587-593. DOI: 10.1016/j.prosdent.2015.04.016

Carozzi F.G., Poggi C., 2015, Mechanical properties and debonding strength of Fabric Reinforced Cementitious Matrix (FRCM) systems for masonry strengthening, Composites Part B: Engineering, 70, 215-230. DOI: 10.1016/j.compositesb.2014.10.056

García T.E., Rodríguez C., Belzunce F.J., 2014, Estimation of the mechanical properties of metallic materials by means of the small punch test, Journal of alloys and compounds, 582, 708-717. DOI: 10.4028/www.scientific.net/kem.741.116

Gong H., Wang K., Strich R., 2015, In vitro biodegradation behavior, mechanical properties, and cytotoxicity of biodegradable Zn–Mg alloy, Journal of Biomedical Materials Research Part B: Applied Biomaterials, 103(8), 1632-1640. DOI: 10.1002/jbm.b.33341

Jiang C., Fan K., Wu F., 2014, Experimental study on the mechanical properties and microstructure of chopped basalt fibre reinforced concrete, Materials & Design, 58, 187-193. DOI: 10.1016/j.matdes.2014.01.056

Shu X., Graham R.K., Huang B., 2015, Hybrid effects of carbon fibers on mechanical properties of Portland cement mortar, Materials & Design (1980-2015), 65, 1222-1228. DOI: 10.1016/j.matdes.2014.10.015

Tymrak B.M., Kreiger M., Pearce J.M., 2014, Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions, Materials & Design, 58, 242-246. DOI: 10.1016/j.matdes.2014.02.038

Veleva L., Schaeublin R., Battabyal M., 2015, Investigation of microstructure and mechanical properties of W–Y and W–Y2O3 materials fabricated by powder metallurgy method, International Journal of Refractory Metals and Hard Materials, 50, 210-216. DOI: 10.1016/j.ijrmhm.2015.01.011