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THREE-DIMENSIONAL DISPLACEMENT MEASUREMENT OF INFLATED AIR-SPRING SHELL USING STEREO-CORRELATION TECHNIQUE

MĚŘENÍ 3-D POSUVU PLÁŠTĚ NAFUKOVANÉ PNEUMATICKÉ PRUŽINY POMOCÍ METODY STEREOKORELACE

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The three-dimensional (3-D) displacements of inflated cylindrical shell of air-spring made of composite material with rubber matrix reinforced by textile cords are measured by the application of the stereo-correlation technique. The 3-D coordinates of points in the central part of air-spring shell are obtained at different stages of loading by the matching of a series of stereo images. By the use of the nonlinear optimization technique, the deformations of the air-spring shell are determined. The proposed method may be applied to measurements of the three-dimensional deformations of different structures.

Posuvy a deformace pláště pneumatické pružiny, který je zhotoven z kompozitu s pryžovou matricí vyztuženou kordy, jsou určeny pomocí metody stereokorelace. Jsou stanoveny 3-D souřadnice bodů v centrální části pláště při postupném zatěžování vnitřním přetlakem triangulací ze souřadnic serie digitálních snímků dvou kamer. Deformace pláště jsou vypočteny pomocí nelineárních nejmenších čtverců. Metodu lze použít k určení 3-D deformací různých objektů.

Keywords *Experimental mechanics, stereovision, digital image correlation, 3-D metrology.*

Klíčová slova *Experimentální mechanika, stereovidění, korelace digitálních snímků, 3-D metrologie.*

Introduction

In the last decade, a non-contact optical technique, digital image correlation (DIC), is developed for the displacement determination of the object under loading. The 3-D displacement measurement requires the use of at least two synchronized cameras acquiring images of the loaded specimen from different viewing angles. By determining corresponding image points accross views from the different cameras and tracking their movement throughout the loading cycle, the shape and deformation can be reconstructed by the triangulation.

Several works have been done on 3-D displacement and deformation measurement using two cameras or single camera (Luo et al., 1998; Garcia et al., 2001, 2002). The stereocorrelation was applied by Luo et al. (1998) to the measurement of curved surfaces. The stereovision technique

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has been used to measure 3-D strains of formed sheet metal parts and of inflated elastomeric membranes (Garcia et al., 2002). The ability of a DIC technique to capture the heterogenous deformation fields appearing during compression of ultra-light open-cell foams is described in paper of Wang and Cuitino (2002).

Camera calibration is a fundamental step in 3-D computer vision, specially when the metric informations are required for applications involving accurate dimensional measurements. Camera calibration is the process of determining the internal camera geometric and optical characteristics (intrinsic parameters) and the 3-D position and orientation of the camera frame relative to a certain world coordinate system (extrinsic parameters) and the determination of the geometry of the stereo rig (the relative position and orientation of the two cameras).

Next task is to determine the corresponding points between pairs of stereo-images (stereo-matching) and retrieval of the corresponding points in the series of images taken by the left camera (or the right one) at different stages of loading (temporal matching). The matching techniques and corresponding algorithms can be divided into major categories: area-based, feature-based and hybrid (Cardenas-Garcia et al., 1995). Area-based algorithms which use image intensity level distribution to find the best match between a pair of images are comprehesively evolved in works of Garcia and Orteu (2001, 2002).

The last step is the triangulation – the determination of the 3-D coordinates of the specimen surface from the disparity value of surface points at different loading steps and then calculation of the displacements and the deformation. In this paper, the 3-D displacements and deformations of inflated cylindrical shell of air-spring are measured accurately by the application of the stereo-correlation technique.

Experiment

The black air-spring sheathing was marked with the white spray paint which resulted in a fine textured random pattern (Fig.1).

Fig. 1. The air-spring is pressurized

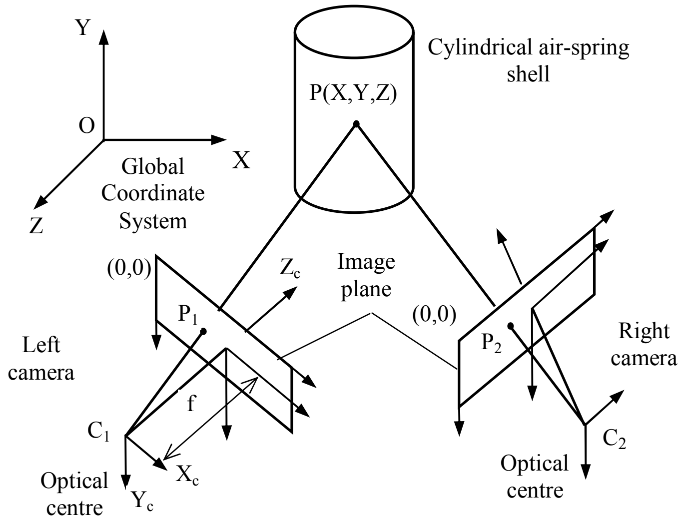

Fig. 2. Schematic diagram of Camera model

The air-spring was loaded and unloaded gradually by pressurized air by step 0.02 MPa in the range 0–0.3 MPa and then by step 0.05 MPa up to 0.6 MPa to guarantee a small deformation (<20%) between each image of the sequence. Images of the size of 1280x960 pixels were recorded by two digital cameras Minolta mounted on a special support. The axial force and the inner pressure were measured and stored at every stage of loading.

Calibration

We used camera calibration toolbox for Matlab which is developed by Bouguet (2004). Calibrating stereo rig is dealt with by calibrating each camera independently and then applying geometric transformation of the external parameters to determine the geometry of the stereo rig. We used the checkerboard pattern with 10 mm squares. The result of calibration:

Intrinsic parameters
Focal Length: fc_left = [2798.67375 2807.58737]
fc_right = [2986.40129 2994.80468]
Principal point: cc_left = [670.04807 585.78871]
cc_right = [685.64123 605.86915]
Distortion: kc_left = [-0.00395 3.24668 0.01156 0.00749 0.00000]
kc_right = [0.07555 1.77120 0.01461 0.01260 0.00000]

Extrinsic parameters (position of right camera wrt left camera):
Rotation vector: om = [0.01478 0.47729 0.03584]
Translation vector: T = [-345.41229 -5.64866 123.96245]

Stereo and temporal matching

The area-based correlation function was calculated for a grid of 5x5 pixel in the central part of every image. The images were not rectified and the epipolar line was calculated for every point of interest. The disparity for every point was calculated and the spatial coordinates of surface points vere determined (Fig. 3). The computed mean radia of air-spring shell at loaded and unloaded stages are shown in Fig. 4.

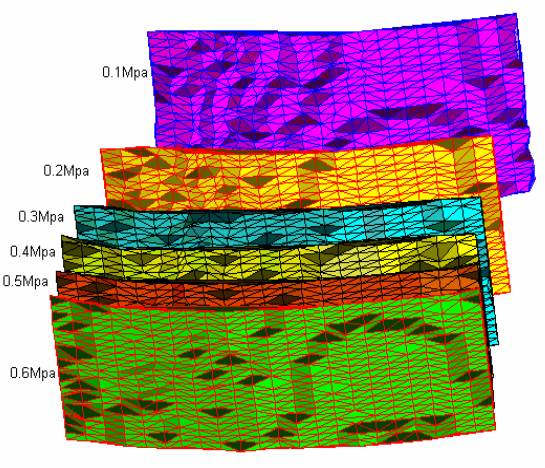

Fig.3. The 3-D displacements of air-spring

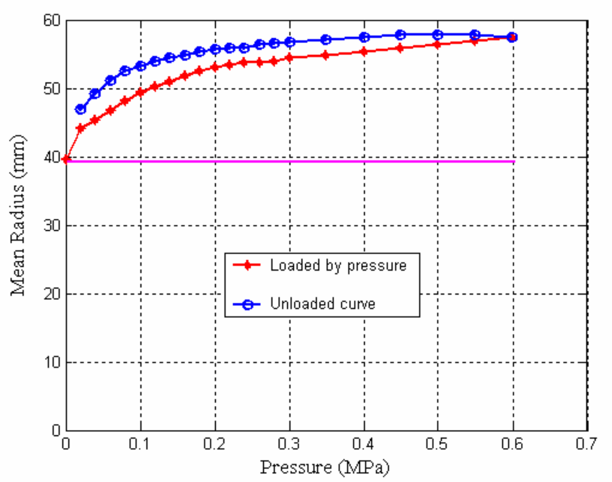

Fig. 4. The mean computed radia

Conclusion

An experimental method through using two digital cameras for 3-D displacement and deformation measurement is presented. The 3-D coordinate of points in the central part of air-spring shell are obtained at different stages of loading using digital image correlation. 3-D displacements and deformations of inflated cylindrical shell part of air-spring made of composite material with rubber matrix reinforced by textile cords are measured by the application of the stereo-correlation technique. By the use of the nonlinear optimization technique, the equation of cylindrical surface of air-spring shell is solved to obtain a set of parameters, the direction cosine of the centerline of the cylinder, the point of intersection of the centerline of the cylinder with the XZ-plane, and the radius of the cylinder. The computed radius of the cylinder is compared to the measured value to evaluate the measurement error. Results indicate that the stereo-correlation technique may accurately measure the curved surface in various curvatures. Hence, the analysis method proposed in our paper may be further applied to study other deformation problems such as piping under pressure, and fracture problems.

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