3D Reconstruction from Multiple Images Acquired using a Scanning Electron Microscope (SEM) (2001-)

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The goal of this work is to develop the methodology for obtaining accurate, three-dimensional measurements of object deformation using a scanning electron microscope. Calibration methods are being developed for the SEM that include novel distortion correction approaches. The 3D reconstruction of the specimen surface is computed using multiple views acquired through motion of the SEM specimen's stage. Since the displacement information obtained from typical SEM stages is not sufficiently accurate for 3D deformation measurements, we are employing a photogrammetric approach to estimate the movements of the sample using specimen images. Using these results, the 3D deformation measurements are computed using a bundle adjustment method that is also common to a range of photogrammetric methods.

Keywords: SEM, 3D measurements, photogrammetry.

References

[1] N. Cornille, D. Garcia, M.A. Sutton, S. McNeill, J.J. Orteu, "Automated 3-D Reconstruction Using a Scanning Electron Microscope", SEM Conference on Experimental and Applied Mechanics Charlotte, North Carolina (USA), 2-4 June 2003.

Measurement of 3-D shapes or 3-D displacement fields using a stereo-correlation based method (1997-2001)

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Many applications dealing with the mechanical behaviour of materials require the measurement of displacement fields or deformation fields. In order to attain these measurements, optical methods have become unavoidable due to their non-intrusive approach, their high spatial resolution, their high sensitivity, the large size of their examinated field, and the increasing power of the computers that now allow the processing of huge quantities of data.
In this context, we have developed a system for measuring 3-D shapes or 3-D displacement fields using a stereo-vision approach (by stereo-correlation). This method allows: (1) the measurement of the 3-D object shape using a single pair of stereoscopic images of this object and (2) the measure of the 3-D displacement field using at least two pairs of stereoscopic images of an object corresponding to two states of its deformation (or the processing of a sequence of pairs of images acquired during the deformation).
The main topics developed in our work are: the strong calibration of a camera or a stereovision sensor, the 3-D reconstruction by stereovision, the measurement of the 3-D displacement field using a combined stereo-correlation and tracking approach in a sequence of images. Due to the metrology aspect of this research we have paid particular attention to the accuracy of the underlying methods (quality of the calibration, quality of the image matching, subpixel correlation,...). This work has been succesfully applied to the sheet metal forming (measurement of 3-D shapes and 3-D displacement fields of the stamped parts), to polymer forming (measurement of the 3-D displacement field on a blown elastomere membrane), and to the study of the mechanical behaviour of a refractory ceramic reinforced with metallic fibers (measurement of 3-D displacement fields during a tensile test).

Keywords: camera calibration, stereovision, correlation based image matching, non-contacting 3-D metrology, computer vision based experimental mechanics.

References

[1] J.J. Orteu, H. Al-Haddad, S. Lacroix, "Mesure de déformations 3D par stéréocorrélation", Colloque Photomécanique 98, Marne la Vallée (France), 14-16 Avril 1998.

[2] J.J. Orteu, "Mesure de déformations 3D par stéréovision", Congrès Numérisation 3D 98, Paris (France), 27-28 Mai 1998.

[3] D. Garcia, J.J. Orteu, "Measure of Local Deformations on Stamped Sheet Metal Parts using Stereo-correlation", International Deep Drawing Research Group (IDDRG'99) – Meeting of the Working Groups, Birmingham (UK), 7-9 June 1999.

[4] D. Garcia, J.J. Orteu, "3D Deformation Measurement using Stereo-correlation applied to the Forming of Metal or Elastomer Sheets", International Workshop on Video-Controlled Materials Testing and In-Situ Microstructural Characterization, Nancy (France), 16-18 November 1999.

[5] D. Garcia, J.J. Orteu, "Mesure de formes et de déformations 3D par stéréo-corrélation : application sur des tôles minces embouties", Colloque "Nouveaux Moyens Optiques pour l'Industrie II", Mittelwihr, Alsace (France), 17-19 Novembre 1999.

[6] D. Garcia, J.J. Orteu, "Photomécanique: mesures 3D de champs de déplacements et de déformations par stéréo-corrélation d'images", Journées GDR-PRC ISIS "Numérisation et Modélisation 3D", Paris (France), 24-25 Janvier 2001.

[7] D. Garcia, J.J. Orteu, "3D Deformation Measurement using Stereo-correlation applied to Experimental Mechanics", 10th FIG International Symposium on Deformation Measurements, Orange, California (USA), 19-22 March 2001.

[8] D. Garcia, B. David, J.J. Orteu, T. Cutard, E. Cailleux, "Application de la stéréovision à l'étude du comportement de bétons renforcés de fibres métalliques", Colloque Photomécanique 2001, Futuroscope, Poitiers (France), 24-26 Avril 2001.

[9] D. Garcia, "Mesure de formes et de champs de déplacements tridimensionnels par stéréo-corrélation d'images", PhD thesis, Institut National Polytechnique de Toulouse (France), 21 Décembre 2001.

[10] J.J. Orteu, "Mesure 3D de formes et de déformations par stéréovision", Techniques de l'Ingénieur, Traité Génie Mécanique – Travail des matériaux, BM 7015, Avril 2002.

[11] D. Garcia, J.J. Orteu, T. Cutard, E. Cailleux, "Application of Stereovision to the Mechanical Characterization of Refractory Ceramics Reinforced with Metallic Fibers", SEM Conference on Experimental and Applied Mechanics, Milwaukee, Wisconsin (USA), 10-12 June 2002.

[12] D. Garcia, J.J. Orteu, L. Penazzi, "A Combined Temporal Tracking and Stereo-correlation Technique for Accurate Measurement of 3D Displacements: Application to Sheet Metal Forming", 9th International Metal Forming Conference, Birmingham (UK), 9-11 September 2002.

[13] D. Garcia, J.J. Orteu, L. Penazzi, "A Combined Temporal Tracking and Stereo-correlation Technique for Accurate Measurement of 3D Displacements: Application to Sheet Metal Forming", Journal of Materials Processing Technology 125-126 (2002) 736-742, Elsevier Science, September 2002.

[14] J.J. Orteu, D. Garcia, M. Devy, "Mesure de formes et de champs de déplacements tridimensionnels par stéréo-corrélation d'images : applications en mécanique expérimentale", Photoniques – Le Journal de la Société Française d'Optique (à paraître en 2002).

[15] D. Garcia, J.J. Orteu, M. Devy, "An Enhanced Stereo-correlation Technique for Accurate 3D Measurements: Application to Experimental Mechanics", IEEE Transactions on Pattern Analysis and Machine Intelligence (soumis le ? 2002).

Accurate Calibration of a Stereovision Sensor for 3D Metrology Applications (1994-2001)

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An important task in 3D computer vision is camera calibration, specially when metric informations are required for applications involving accurate dimensional measurements. Calibrating a camera involves determining its intrinsic parameters and its position and orientation with respect to a world reference frame.
Calibrating a stereovision sensor made up of two cameras involves determining the intrinsic parameters of each camera and the relative position and orientation between the two cameras.
We have developed an original and flexible technique to easily calibrate a camera or a stereovision sensor. Lens distortion is taken into account. The technique only requires the camera or the stereovision sensor to observe a (planar) pattern shown at a few different orientations. The motion of the pattern need not be known and the pattern itself can be imprecise.
This technique leads to a highly accurate calibration.

Keywords: camera calibration, stereovision, photogrammetry, 3D metrology.

References

[1] J.J. Orteu, V. Garric, M. Devy, "Camera calibration for 3D reconstruction : application to the measure of 3D deformations on sheet metal parts", European Symposium on Lasers, Optics and Vision in Manufacturing (EUROPTO), Munich (Germany), 16-20 June 1997.

[2] M. Devy, V. Garric, J.J. Orteu, "Camera calibration from multiple views of a 2D object, using a global non linear minimization method", IEEE/RSJ International

Conference on Intelligent Robots and Systems (IROS'97), Grenoble (France), 7-11 September 1997.

[3] D. Garcia, J.J. Orteu, M. Devy, "Accurate Calibration of a Stereovision Sensor: Comparison of Different Approaches", Vision, Modeling, and Visualization 2000, Saarbrücken (Germany), 22-24 November 2000.

[4] D. Garcia, J.J. Orteu, M. Devy, "Calibrage précis d'un capteur de vision stéréoscopique", Congrès ORASIS 2001, Cahors (France), 5-8 Juin 2001.

[5] D. Garcia, "Mesure de formes et de champs de déplacements tridimensionnels par stéréo-corrélation d'images", PhD thesis, Institut National Polytechnique de Toulouse (France), 21 Décembre 2001.

[6] D. Garcia, J.J. Orteu, M. Devy, "Accurate Calibration of a Stereovision Sensor for 3D Metrology Applications", Image and Vision Computing, Elsevier Science (soumis le 10 juillet 2001).

An easy-to-use 3D scanner for object modelling using a single camera (1999-2000)

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Our goal was to develop an efficient general public tool for the modelling of any 3D object or scene from a single off-the-shelf camera, with no specific hardware required. Before initial use, the camera simply needs to be calibrated in order to obtain its intrinsic parameters. The off-line camera calibration procedure has been fully automatised. The system works in four main stages:

- acquisition of two views of the scene to be digitized from two different viewpoints,
- computation of the camera displacement between the two views,
- feature detection for stereo matching,
- 3D reconstruction, meshing and texturing.

Finally, if a full 360 model is required, several 3D point clouds can be merged to generate a 3D mesh.
The developed software has been used to obtain the 3D model of many real 3D scenes.

Keywords: 3D modelling, photogrammetry.

References

[1] B. Aubé, D. Garcia, J.J. Orteu, "Procédé de création automatique de maquette numérique à partir de couples d'images stéréoscopiques", Brevet N° 99.14237 déposé le 12 novembre 1999.

[2] B. Aubé, D. Garcia, J.J. Orteu, "Un scanner 3D pour la modélisation d'objets, simple à utiliser et n'utilisant qu'une seule caméra – An easy-to-use 3D scanner for object modelling using a single camera", SCANNING 2000 : The Scanning European Meeting Point, Fifth Edition, Paris (France), 24-25 May 2000.

Continuous in-situ measurement of quenching distortions using computer vision (1998-2000)

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A heat treatment vacuum furnace equipped with a CCD camera is used to follow the shape evolution of two axisymmetric steel samples during gas cooling. The experimental results are compared with numerical simulations performed with the finite element technique. A good agreement is obtained between the theoretical predictions and the experiments.
The shape evolution of metallic samples are measured experimentally and simulated numerically during all the cooling process. The accuracy of the measurement is 0.01 millimetre, while the dimensions of the samples are 40 millimetres diameter and 80 millimetres height. Stepwise increasing hole diameters are used in the samples to amplify the shape changes during quenching.
The first steel sample does not exhibit phase changes during cooling. The shape evolution is only due to thermal shrinking. Since residual distortions are not observed, the thermal gradients generated during these experiments are not large enough to induce plastic deformation.
The second steel sample presents a martensitic transformation during cooling. The shape changes are thus due to both thermal shrinking and phase changes. The residual distortions observed can be attributed to transformation plasticity. It turns out that this physical phenomenon can be studied by the experimental set-up we have developed.

Keywords: quenching, distortions, measurements, computer vision.

References

[1] S. Claudinon, P. Lamesle, J.J. Orteu, R. Fortunier, "Utilisation des éléments finis pour la prévision des déformations en traitement thermique", Journées franco-allemandes ATTT-AWT sur les déformations en traitement thermique, Belfort (France), 24-25 Avril 1997.

[2] S. Claudinon, J.J. Orteu, P. Lamesle, R. Fortunier, "Mesure par voie optique des distorsions au traitement thermique de matériaux métalliques", Colloque Photomécanique 98, Marne la Vallée (France), 14-16 Avril 1998.

[3] S. Claudinon, R. Fortunier, P. Lamesle, J.J. Orteu, "Suivi continu par vision de la distorsion d'outils au traitement thermique", 37èmes Journées du Cercle d'Étude des Métaux – "les aciers pour moules et outils", Albi (France), 27-28 Mai 1998.

[4] S. Claudinon, "Contribution à l'étude des distorsions au traitement thermique: suivi continu par vision artificielle et simulation numérique par éléments finis", PhD thesis, École des Mines de Paris (France), 7 Février 2000.

[5] S. Claudinon, P. Lamesle, J.J. Orteu, R. Fortunier, "Monitoring distortions of metallic parts during heat treatment", 5th ASM Heat Treatment and Surface Engineering Conference in Europe, Gothenburg (Sweden), 7-9 June 2000.

[6] S. Claudinon, P. Lamesle, J.J. Orteu, R. Fortunier, "Amélioration de la connaissance et de la prévision des distorsions d'aciers au traitement thermique", Journées d'Automne 2000 de la Société Française de Métallurgie et de Matériaux, Paris (France), 17-19 Octobre 2000.

[7] S. Claudinon, P. Lamesle, J.J. Orteu, R. Fortunier, "Contribution à l'étude de la distorsion au traitement thermique : suivi continu par vision artificielle et simulation numérique par éléments finis", Colloque Photomécanique 2001, Futuroscope, Poitiers (France), 24-26 Avril 2001.

[8] S. Claudinon, P. Lamesle, J.J. Orteu, R. Fortunier, "Continuous in-situ measurement of quenching distortions using computer vision", Journal of Materials Processing Technology 122 (2002) 69-81, Elsevier Science, March 2002.

Overheat, fire, smoke and freight movement detection algorithms based on CCD sensor for aircraft cargo surveillance (1997-2000)

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From 1997 to 2000, the CROMeP has been involved in a research project dealing with aircraft security. We have developed a video-surveillance system able to detect fire, smoke, hot points and freight movements in an aeroplane freight-hold. The system is based on a camera-based sensor connected to a real-time computer which analyses the images.
The originality ot the approach is to use a single sensor to detect many different phenomenons (multi-functions mono-sensor approach). For each phenomenon to be detected, we have established its discriminant parameters and developed the image processing software to perform the detection.
Our main contribution has been:

- the performance characterisation of a CCD camera in the near infrared band for a coupled measurement of radiometric and geometric characteristics,
- the development and testing of the image processing software which required the design of specific test facilities.

Through this project we have developed skillness in high resolution thermal imaging in the near infrared, in thermal and geometric calibration of CCD cameras, in 3D pose estimation from monocular vision and more generally speaking in image processing.
The project is now finished. A prototype has been developed and intensively tested at the laboratory level. A flying prototype is now being tested.

Keywords: surveillance, aircraft, cargo compartment, computer vision.

References

[1] T. Sentenac, J.J. Orteu, Y. Le Maoult, M. Devy, G. Boucourt, "Load Movement Measurement using a Near-Infrared CCD Camera for Aircraft Cargo Surveillance", 8th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'2001), Antibes Juan-les-pins (France), 15-18 October 2001.

[2] T. Sentenac, Y. Le Maoult, J.J. Orteu, G. Boucourt, "Evaluation of a charge-coupled-device-based Video Sensor for Aircraft Cargo Surveillance", Optical Engineering 41(4) 796-810, April 2002.

Glass bottle forming control : on-line measurement of gob position and shape using computer vision (1995-1997)

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The forming of a glass bottle involves a gob of molten glass to be fed into a blank mould before blowing. During its travel from the feeder to the mould, the gob undergoes some deformation which can affect the penetration into the mould and can lead to poor quality bottles. In order to control the loading and optimize the forming process, we have equipped a production line with a computer vision sensing system to measure, in real-time, the shape of the gob and its position with respect to the mould axis.

Keywords: glass industry, glass forming control, molten glass inspection, linear vision.

References

[1] B. David, J.J. Orteu, Ph. Mérour, "Glass bottle forming control : on-line measurement of gob position and shape using computer vision", 2nd European Congress of Chemical Engineering – 2ème Congrès Européen de Génie des Procédés, Montpellier (France), 5-7 October 1999.

[2] B. Riffard, B. David, C. Firmin, J.J. Orteu, J.G. Postaire, "Computer vision systems for tuning improvement in glass bottle production: on-line gob control and crack detection", 5th International Conference on Quality Control by Artificial Vision (QCAV'2001), Le Creusot (France), 21-23 May 2001.

[3] J.G. Postaire, J.J. Orteu, "Contrôle des procédés de fabrication dans l'industrie du verre par vision artificielle", invité à la Journée "Apports de la Vision Industrielle au Contrôle Qualité" du pôle Essais Non Destructifs COFREND Grand Sud-Ouest, Toulouse (France), 30 Mai 2001.

Real-time inspection of pre-weathered zinc based on computer vision (1994-1995)

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UNION MINIÈRE is an international firm that has developed a special process, called preweathering, which gives rolled zinc sheets a natural looking patina or a slate gray colour. The strip of preweathered zinc can be affected by surface defects caused by the roll-mill or by the preweathering process. We have equipped a production line of preweathered zinc in the plant with a computer vision based system in order to automatically inspect one side of the strip. The system is composed of a personal computer system, a light source, a line scan camera and an acquisition board. The basic purpose of this system is to provide effective on-line inspection.
The main problems that have been solved are (i) that the imperfections show a considerable variation in length, from a few centimetres in the case of local defects, to several decimetres in the case of periodic spaced defects due to rollers, (ii) that the contrast between the local defect and the strip is poor, (iii) that the grayness varies across the width of the strip, (iv) that the grayness varies across the length of the roll.
The real-time inspection system is currently running in the plant.

Keywords: visual inspection, linear vision, real-time, industrial system, preweathered zinc.

References

[1] L. Duvieubourg, J. Caron, J.J. Orteu, Ph. Révolte, "Real-time inspection of preweathered zinc based on computer vision", Conference on Machine Vision Applications in Industrial Inspection 1996, San Jose, California (USA), 31 January - 1 February 1996.

[2] J. Caron, L. Duvieubourg, J.J. Orteu, Ph. Révolte, "Automatic inspection system for strip of preweathered zinc", International Conference on Applications of Photonics Technology 1996 (ICAPT'96), Montreal (Canada), 29 July - 1 August 1996.