Computers in Industry 64 (2013) 1301–1315

Contents lists available at SciVerse ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Application of 3D digital image correlation in maintenance and process control in industry

Marcin Malesa [a,*], Krzysztof Malowany [a], Urszula Tomczak [b], Bartłomiej Siwek [c], Małgorzata Kujawińska [a], Anna Siemińska-Lewandowska [b]

[a] Institute of Micromechanics and Photonics, Warsaw University of Technology, 8 A. Boboli St., 02-525 Warsaw, Poland
[b] The Institute of Roads and Bridges, Warsaw University of Technology, 16 Armii Ludowej St., 00-637 Warsaw, Poland
[c] KSM Vision Ltd., 9/117 Sokolowska St., 01-143 Warsaw, Poland

ARTICLE INFO

Article history:
Received 2 October 2012
Received in revised form 11 March 2013
Accepted 27 March 2013
Available online 7 May 2013

Keywords:
Digital image correlation
Thermovision
Displacement measurement
Civil engineering
Power plants

ABSTRACT

3D digital image correlation method is widely used for displacements measurements in laboratory conditions and for experimental applications in industries. In this paper we present enhancements of the standard method, which enable application of 3D DIC for in situ monitoring and process control in industries and out-door environment. Enhancements concern software modifications (new visualization methods and a method for automatic merging of data distributed in time) and hardware improvements (protecting equipment against hard environmental conditions).

The modified 3D DIC system is applied in two interesting cases: measurements of steel struts at construction site and measurements of a pipeline in an intermediate pumping station. In both applications we additionally used an infrared camera in order to correlate deformations of measured objects with temperature changes.

1. Introduction

In the domain of experimental mechanics and vision-based optical metrology, digital image correlation (DIC) is a validated and well-established method for determining displacements in a wide range of test objects [1–3]. The experimental setup for DIC measurements is very simple. It requires images acquisition hardware, and a computer system for synchronization, data storage and processing. 3D DIC technique provides non-contact, full-field measurements of displacements and strains of an object subjected to mechanical, thermal or environmental loads. All mentioned features make 3D DIC system a good candidate for implementation in industry [4,5]. Development of the standard DIC method within such application areas as measurements of discontinuous fields [6,7], measurements of large deformations [8], or optimization for measurements in extreme environments [9] enable more advanced in situ implementations. Good examples of in situ applications of DIC have been presented in deflection measurements of bridges [10], monitoring of displacement of continuously active landslides in South French Alps [11] and measurement of a velocity field in deformation zones in cold rolling [12]. A number of applications of DIC method in industry have significantly increased in recent years. However, to the best knowledge of authors, there is still a lack of published implementations of the method into practice for maintenance and process control or long-term monitoring in industrial and civil engineering applications. In order to achieve this goal the standard method needs to be tuned to any particular application and needs to be accepted by engineers responsible for a certain case.

Industrial applications need regular testing for the lifetime, movement, strength, and performance of machines and structures during production process. Measurement equipment applied for these kind of tasks need to be adopted to work in hard environmental conditions. Furthermore a long-term monitoring of objects or processes is often required. In such situations, the use of laboratory test methods is particularly challenging or even impossible. On the other hand, a typical measurement accuracy of DIC can be in many cases relaxed in industry. Taking into account these facts we have developed a method for automatic merging of DIC data distributed in time. Such method is highly required when monitoring should be performed over a long period of time, but measurement equipment due to various reasons cannot stay at the site. Another required enhancement of the standard DIC measurement is adding a new modality, namely temperature or distribution of temperature changes. In the presented applications we used a simultaneous capture of temperature distribution and displacements maps at an object surface. Similar approach was introduced by Orteu in 2008 when he performed simultaneous measurements

* Corresponding author. Tel.: +48 608571909.
E-mail address: m.malesa@mchtr.pw.edu.pl (M. Malesa).

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http://dx.doi.org/10.1016/j.compind.2013.03.012

of 3D shape, strain and temperature fields with utilization of CCD camera operating in NIR [13]. Maynadier in 2012 [14] presented another method for combined measurements of temperature and strain maps, in which all data was acquired with a single infrared camera. Somewhat different approach was presented by Chrysochoos [15] and Kujawinska [16], who utilized separate devices for acquisition of infrared and white-light images. This approach has been also implemented in the presented applications

The paper is organized as follows: in Section 2 we report on hardware and software enhancements, which have been introduced in order to fulfill the needs of industrial customers and in order to adapt 3D DIC system to out-of-laboratory conditions; in Section 3 we present application that concerns measurements of building struts' deformations; second application, presented in Section 4 illustrates the case of monitoring of a pipeline subjected to a thermal load. The examples are purposely chosen from different fields in order to present versatility of DIC method in industrial applications. Description of the first application is more detailed as it includes implementation of the method for automatic merging of data distributed in time. The examples presented in the paper show evidently the differences between 3D DIC practice in industries and in its standard, scientific or laboratory applications.

2. Digital image correlation for industrial applications

In the standard DIC [2] the reference image (the first image of the series in the most cases) is divided into small subsets (subimages). The software searches for the most similar subset in all other images, using the maximum cross-correlation function criterion (Fig. 1). The center point of the most similar subset found in a deformed image defines the displacement vector. In order to facilitate matching, each subset needs to be sufficiently distinct in the aspect of intensity variations. Therefore a random speckle pattern is applied (e.g. spray paint, sticker paper, water decals) to the object within the area of interest (AOI – area of acquired images in which displacement maps are calculated). In order to apply DIC in industrial applications we introduced enhancements in both: software and hardware.

The main goal of hardware enhancement was to minimize the influence of environmental conditions (high temperature gradients and dustiness) on DIC measurements and also to secure the equipment. Hardware enhancements and a visualization method are rather incremental developments of DIC and were necessary in order to ensure applicability of DIC for particular measurement tasks.

Innovative software enhancements enable long-term measurements. Long-term measurements refers to a case, when 3D DIC setup has to be relocated between consecutive measurements. Two-dimensional version of the method has been described by authors in Ref. [17].

2.1. Hardware enhancements

A standard, laboratory 3D DIC system includes two cameras mounted on a tripod, a reflector and a control computer. For in situ, industrial applications in maintenance tasks or process-control there is a need of much more flexibility in a configuration of a measurement setup [9]. A good solution is aluminum constructional profiles, which are often used in industrial applications of measuring systems. Profiles can be used to build scaffolds or rigs and can be easily rearranged. In our case we used profiles to build a stiff measurement rig. The configuration of rigs depends on application and an object's location; rigs can be mounted directly to tripods or to stationary elements close to the measured object. The flexibility with DIC setup configuration is also important as often an access to the selected area of interest is hindered. The maximum elongation of 1 m profile due to thermal expansion in typical environmental conditions is about 0.3 mm. For the most industrial applications (including examples presented in the paper) this is an acceptable level. However, in cases when better accuracy is necessary we can use profiles/bars made of invar material (the material with an extremely low thermal expansion coefficient).

Artifacts used for the standard stereo-calibration of 3D DIC [2] setup are made of dibond material. Dibond is a strong, flat and lightweight material which is weather and dust-resistant. It is an aluminum composite panel material (ACP) and it is formed by laminating a central core of thermoplastic material with an outer skin of aluminum sheet (18). The most important properties of dibond material are presented in Table 1.These values prove the high applicability of dibond material for in situ calibration of the measurement system.The calibration quality during in situ measurements can be significantly decreased because off in-homogenous lighting conditions (e.g. sunlight and shades). In order to avoid an influence of these factors we utilized boards for protection against sunlight during the calibration.Additionally in

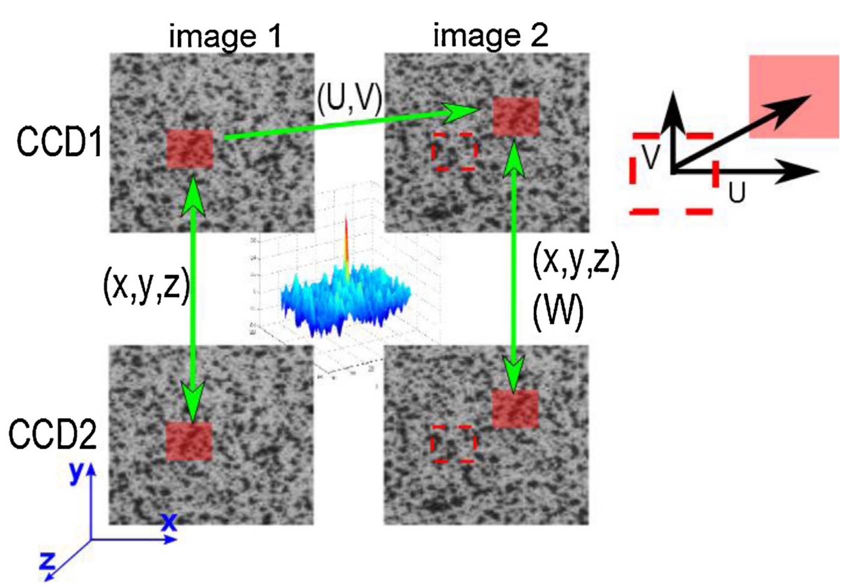

Fig. 1. The principle of 3D digital image correlation method: subimages matching during analysis.