QIRT 10
http://dx.doi.org/10.21611/qirt.2010.157
10th International Conference on Quantitative InfraRed Thermography
July 27-30, 2010, Québec (Canada)

Hybrid Digital Image Correlation/Thermovision system for monitoring of civil engineering structures

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Abstract

In this paper a part of distributed system for civil engineering structures on-line measurement and remote monitoring is presented. The novel concept of combining simultaneous measurements performed by 2D digital image correlation and thermovision methods is described. The experiments performed by means of a single thermographic camera with combined visual sensor are reported and the high applicability of the concept is proven.

1. Introduction

The techniques applied for measurement of displacement/strain and defect detection in civil engineering structures are based on a variety of physical phenomena, among which mechanical, optical, electrical and ultrasound methods prevail. Each of these methods has its unique properties, which predestine it for different types of measurements or/and structural health monitoring. In the case of complex structures and structures exposed to a variety of environmental conditions the information gained from a combination of methods provides the best results [1].

The most required measurands during structural health monitoring are in-plane and out-plane displacements which are directly related to the strains. The wide range of visual methods including interferometric based methods as well as noncoherent light methods including digital image correlation and moiré fringe methods provide displacements in full field of view of the imaging optics and at different level of sensitivity [2,3]. In most of the cases the interferometric methods are too sensitive for monitoring of large scale civil engineering structures. The best fitted method in this case is the digital image correlation method which may be used for both global and local monitoring [4] of such objects. Also in many cases passive and active thermography is used for identification of thermal load distribution as well as assessing and monitoring the health of engineering structures [5], however often the results are difficult for quantitative interpretation.

In the paper we focus on a novel concept of hybrid thermographic/digital image correlation method in which these two techniques are applied for simultaneous monitoring of an investigated structure in order to extend the content of the information captured.

2. Description of the measurement system

In general the hybrid digital image correlation/thermovision (DIC/TNDT) method for monitoring and measurements of displacement and defects is based on four sensors: infrared camera, DIC 2D, DIC 3D and meteo station (Fig. 1). Sensors are connected to central computer, which controls a measurement scenario and transmits data to the data base. A user decides (through an application layer) how to process the actual and stored data and how to visualize data to get rapid access to the information required [1].

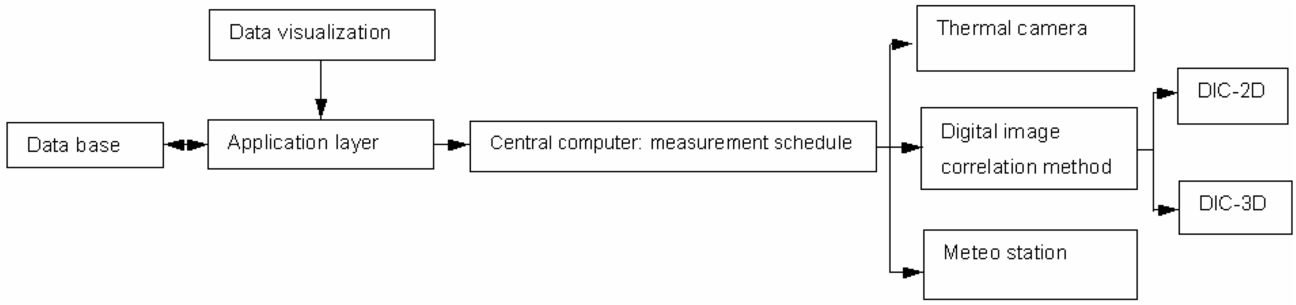

Fig. 1. *The operational scheme of the measurement/data processing system based on DIC and TNDT methods.*

The digital image correlation (DIC) method [4] using a single camera setup (2D DIC) provides the maps of in-plane displacements (u,v), while in a two camera setup (3D DIC) three maps of displacement (u,v,w) are measured for a structure exposed to load within elastic or elasto-plastic ranges. The thermovision camera delivers the actual maps of emissivity

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distribution at the monitored surface (Fig.3) and may include important information about a structure integrity (defects, cracks), thermal insulation, moisture detection and other object features.

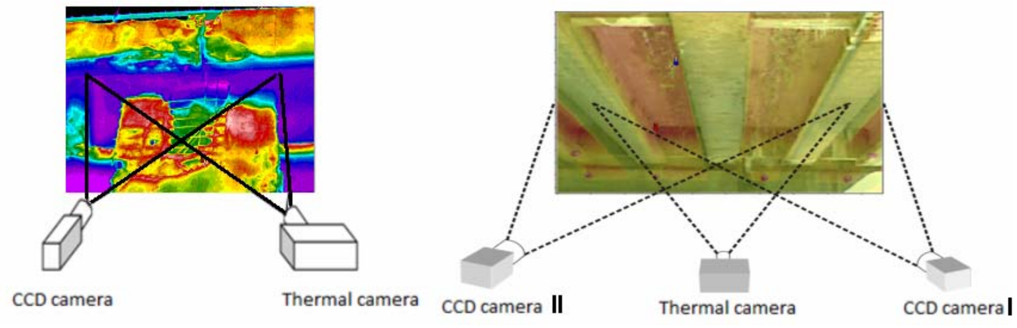

Fig. 2. *The scheme of a) 2D DIC/TNDT and b) 3D DIC/TNDT measurement systems. The photo represents the overlayed images: a bridge structure seen from a) a side and b) the bottom and their colour-coded emissivity distribution.*

Below we will describe in more details the system based on 2D DIC/TNDT which utilizes the visual detector built into thermovision camera so by applying a single device the user may get simultaneously information about in-plane displacement and emissivity of an engineering structure.

The thermographic camera in which the hybrid method has been implemented is VIGOcam v60. The VIGOcam v60 camera is constructed with use of a microbolometric detector array – 640x480 pixels. The new generation, 25mikrom pixel, detector array (640x480 pixels) and imaging optics, ensure high thermal (NETD@70mK) and spatial resolution (0,4mrad) of the camera [6]. The size of sensitive area is 16 x12 mm^2. The VIGOcam v60 has built-in video camera – 1600x1200 pixels (size 3,59 x 2,684 mm^2) The sensor technology utilizes advanced algorithms to cancel Fixed Pattern Noise (FPN), eliminate smearing and reduce blooming.

Although thermal and visible range spectrum images are formed by different imaging channels, they can be overlayed and mixed after their scaling and matching. These procedures are performed by the software available at the camera PC based platform. The data sent to a PC computer can be processed and analysed with the THERM software. This software gives the possibility of using various analytical functions to process temperature distribution data including charts, histograms within user-defined regions. VIGOcam v60 is used for capturing thermal distribution and recording temporal variations in real time. On-line data transmission to computer is performed via USB. Image refresh rate is 25Hz (both in camera and on-line on PC). The camera is equipped with radio link that enables remote control. The image recording can be synchronized with an external control signal.

All these features form an excellent basis to extend the applicability of VIGOcam v60 to 2D digital image correlation method. 2D DIC is the method that employs tracking and image registration techniques for accurate displacement determination. At least two images of an investigated objects at two different states are captured. The surface of an object should have random variations of intensity. DIC is predicated on the maximization of a correlation coefficient that is determined by examining pixel intensity array subsets on two or more corresponding images and extracting the displacement mapping function that relates the images. A custom-built DIC software package developed at Warsaw University of Technology includes an extra effort to enable outdoor measurements under changing lighting conditions [7].

3. Hybrid DIC/thermography method

We assume that a combination of measurement results of two full-field methods, namely: passive thermography and digital image correlation applied to analyze health of an engineering structure provides significantly more information about mechanical behaviour of the structure and allows for proper interpretation of the results. In order to combine these two methods the following algorithm of measurement is proposed:

- capture global and local thermograms of an investigated structure using an infrared camera,
- analyze thermograms in order to find an area with inhomogeneous emissivity which may include a structure defects or the source of internal/external thermal load,
- modify (if necessary) the surface of an object in the field(s) of interest (FoI) with a random pattern,
- perform 2D DIC or 3D DIC measurements using natural (variations of temperatures, wind, passing cars etc) or controlled means of loading and determine a series of displacements fields,
- correlate the knowledge about displacements and temperature fields in order to interpret the results. Support the analysis by FEM if necessary.

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4. Exemplary measurements

In order to show the applicability of the method and sensor two exemplary series of measurements had been performed at buildings which were exposed to internal heating, namely:

- a brick building with a vent,
- a brick building with calcareous front elevation with central heating.

The photo of the brick building with a vent through which warm air was passing and the investigated area are shown in Fig3a. The temperature distribution ap. 50 minutes after staring of warming up of the vent is shown in Fig. 3b.
The texture of bricks was sufficient to perform the image correlation analysis, so no surface modification was perform. The series of images was captured and the first image was compared with the images captured sequentially in time in order to calculate u(x,y) displacement maps (Fig.4).

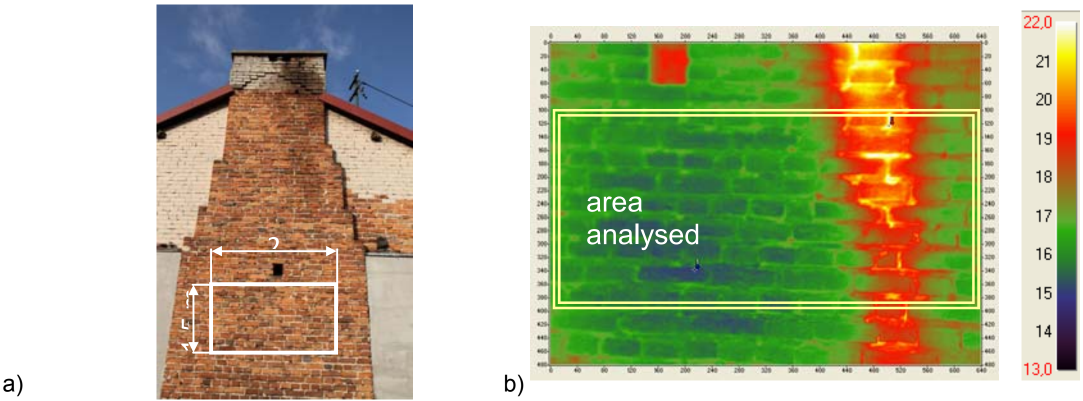

Fig. 3. *a) The wall of a house under investigation and b) the emissivity distribution after 50 min from the beginning of heating process.*

Analyzing the changes of u-displacement fields we notice at first local (Fig.4a) and latter global (Fig.4b,c) expansion of the wall in horizontal (x) direction, however at certain moment the linear expansion at right hand side is stopped (Fig.4d) and displacement stabilizes at an constant value of 3.2mm. It is due to the presence of a partition wall inside the building.

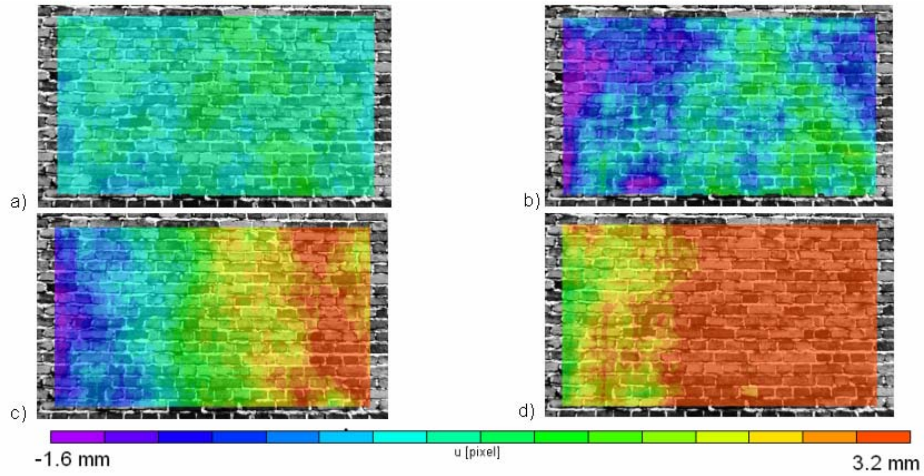

Fig. 4. *The series of u(x,y) displacement maps calculated due to thermal expansion of the brick wall after a) 10 sec, b) 5 min, c) 30min and d) 45min of starting heating process.*

The object for the second experiment was a brick building covered with calcareous front elevation. At the surface of the wall a long crack with 1-2mm width had appeared. The measurements were performed during two hours, by monitoring the wall with DICIR sensor from the distance 1.5m (Fig. 5). It was necessary to modified the wall surface by putting randomly several black flakes. The investigated field of view was 500x500mm. The wall was loaded thermally by increasing the internal temperature through changing the parameters of the central heating system. The exemplary thermograms are shown in Fig.6. They indicate the presence of the crack. Simultaneously with the thermograms the images were captured by the

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video camera and the first image was sequentially correlated with the further series of images (the parameters of correlation procedure: subset: 31pixels, step: 3 pixels) during thermal load changes within 2 hours.

Fig.5. *The photo of experimental setup with DICIR sensor.*

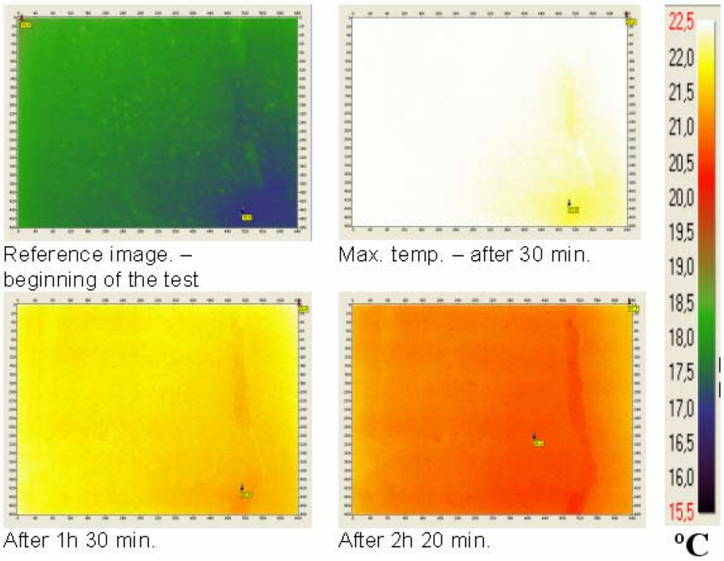

Fig.6. *The exemplary, sequential in time, thermograms obtained in the common IR/DIC measurement field.*

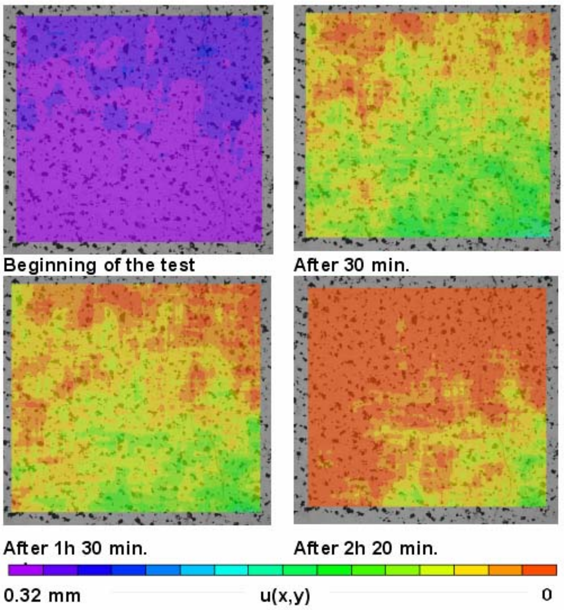

Fig.7. *The sequential maps of u(x,y) in-plane displacements visualized at the background of the object surface with random pattern.*

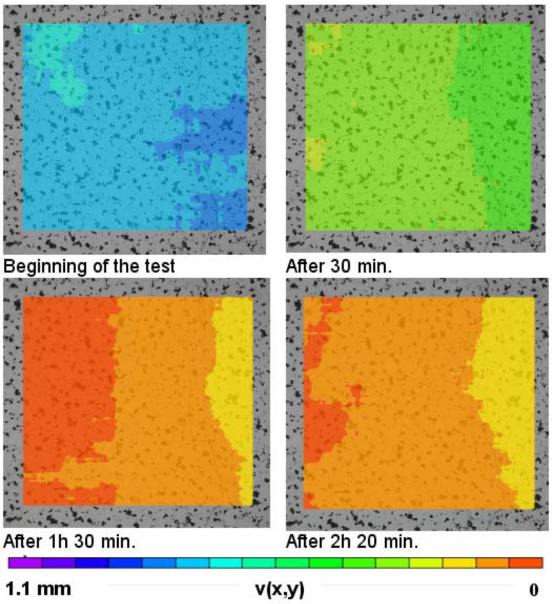

Fig.8. *The sequential maps of v(x,y) in-plane displacements visualized at the background of the object surface with random pattern.*

The exemplary maps of u(x,y) and v(x,y) in-plane displacement fields are presented in Figs.7 and 8. The u(x,y) displacements follow the direction of temperature changes, while the contours of v(x,y) are similar to the crack path. The values of u(x,y) are much smaller than v(x,y).

The summary of these tests is given in Fig.9 through visualization of the maps of temperature difference and v(x,y) displacements difference between the first and last frames captured as well as the plots of temperature and v-displacement

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changes given for points A and B localized at two sides of the crack. The joint analysis of this information allows to consider a variety of sources which may influence the health of the structure under test and predict its further behavior.

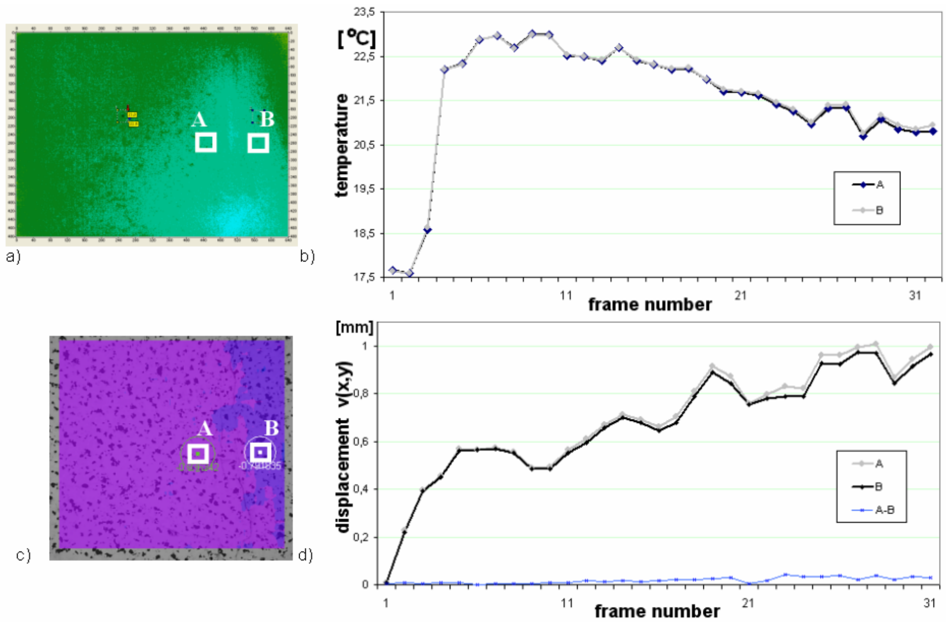

Fig.9. *The maps of a) temperature and b) v(x,y) displacements changes between the first and last frames and the plots of c) temperature and d) displacement changes in points A and B.*

5. Conclusions

The combined thermographic and 2D DIC methods are very useful for both continuous and periodical monitoring of civil engineering structures. DICIR provides quantitative information about a structure behavior under natural or (if possible) controlled loading conditions.

It was proven that often the mechanical behavior (displacement and strain maps) of a structure would be difficult to interpret without the knowledge about the emissivity of an investigated object provided by passive thermography. It can be also expected that the information captured by an active thermography will be enhanced by adding DIC results.

Therefore the combination of both methods in one methodology and in a single instrument providing emissivity and in-plane displacement maps within a single area of interest is suggested for a wide application. In future the further modification of thermal camera by adding two video detectors should be considered in order to extend the capabilities of the system for 3D DIC method.

6. Acknowledgements

The financial support from the project “Health Monitoring and Lifetime Assessment of Structures” – MONIT – POIG.0101.02-00-013/08-00 from the EU Structural Funds in Poland is gratefully acknowledged.

7. References

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