https://doi.org/10.2352/ISSN.2470-1173.2021.18.3DIA-065

3D digital image correlation system for monitoring of changes induced by RH fluctuations on parchment

Athanasia Papanikolaou, Faculty of Mechatronics, Warsaw University of Technology, Warsaw, Poland;
Dorota Dzik-Kruszelnicka, Faculty of Conservation and Restoration of Works of Art, Academy of Fine Arts in Warsaw, Poland;
Sunita Saha, Faculty of Mechatronics, Warsaw University of Technology, Warsaw, Poland;
Malgorzata Kujawinska, Faculty of Mechatronics, Warsaw University of Technology, Warsaw, Poland;

Abstract

One of the most common sources of damage in Cultural Heritage Objects (CHO) such as parchment, oil paintings and historical textiles is relative humidity (RH) changes which cause in-plane and out-of-plane displacements of their surfaces. The best suited method which enables full-field, non-contact displacements measurement with high resolution and sufficient range, is 3D Digital Image Correlation (3D DIC). However, the standard version of DIC requires applying random, good contrast speckle pattern at a surface of the object under investigation. Such requirement is not acceptable for CHOs. In this paper, we analyze the possibility to apply 3D DIC method for monitoring of displacements in selected groups of CHOs without modifying their surface i.e. based on their natural texture. The selection of the data capturing conditions and analysis parameters can lead to successful non-invasive monitoring of CHOs' behavior. The samples studied herein are historical parchments subjected to controlled RH changes that impose in-plane and out-of-plane displacements variations in time.

Introduction

Cultural Heritage objects (CHO) include a variety of techniques and supports, often relatively flexible and considerably sensitive to environmental conditions. To reveal discontinuities or inhomogeneities in their structure, monitor changes while exposed to environmental changes or to assess the compatibility of primary and added materials used in conservation or mounting process, a method capable of tracking of local and global displacements is required. Hence, such a method should combine a large field of view with a sub-millimeter resolution and accuracy of in-plane and out-of-plane displacements measurements and monitoring. The best fitted full-field measurement method which meets such requirements is Digital Image Correlation (DIC). It is a non-contact, vision based method with scalable Field-of-View, scalable and high accuracy and resolution, flexibility of data acquisition frequency and relatively cheap hardware [1].

The main objectives of this paper are: (i) test to what extend 3D DIC can be applied for measurements of objects without any modifications of their surface and (ii) what modifications of the processing path are required for reliable analysis of selected CHOs exposed to varying storage conditions. The main environmental conditions that can vary during the storage of a sample and significantly affect its structural health (including damage) and shape are temperature and humidity [2]. In this paper we are going to focus on the analysis and monitoring of historical parchment specimens response to fluctuating relative humidity (RH). Humidity can often change during the storage of an artifact as it is affected by the season, heating or cooling systems used in the storage room or even by the number of persons present in the room. Parchment material is highly sensitive to changes in RH due to its structure and absorption and desorption properties. Under the influence of water adsorption and desorption parchment undergoes changes to its linear dimensions and thickness, as well as spatial deformations. At the same time, due to its high heterogeneity, these changes are heterogeneous. Monitoring of detail maps of in-plane and out-of-plane displacements at nonmodified parchment samples subjected to different humidity levels for certain time intervals may answer several important questions related to the stability of historical parchments, decisions related to the conservation process as well as setting the proper storage conditions for similar cultural heritage artifacts. In the paper we will try to prove that 3D DIC method can become very useful and efficient metrology tool, which enables to establish new, improved guidelines for long term, cost efficient preservation of parchments collections sensitive to environmental changes.

Description of 3D DIC

Digital Image Correlation is the well-established method for displacements, strains and shape measurements [1]. 2D DIC (with one digital camera) and 3D DIC (with two digital cameras) variations of the method are widely used and accepted in the field of experimental mechanics [3]. The general operation diagram for 2D DIC and 3D DIC methods is shown in Figure 1.

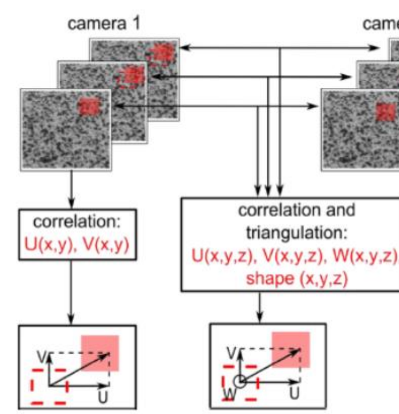

Figure 1: The scheme of DIC operation: 2D DIC system uses one camera to determine in-plane displacements U(x,y) and V(x,y), while 3D DIC systems uses two cameras to measure in-plane and out-of-plane W(x,y) displacements and shape of the tested object

The measurement procedure requires to acquire a set of images of an object under investigation which is subjected to any kind of load (mechanical, environmental). One of the images is selected as a reference image and the remaining images are subjected to the correlation analysis. The reference image is divided into small subimages or subsets. The subsets are subsequently matched against similar subsets in images acquired in different load/environmental conditions states. Repeating the procedure for all subsets from the reference image yields displacements maps, which in the next steps can be used for calculations of strains. As the algorithm makes use of the luminance component of the image, Digital Image Correlation is usually implemented by using monochrome cameras. 2D DIC works by correlating subsets in two images, acquired before and after the event of interest. In 3D DIC the correlation and triangulation methods are combined for additional shape and out-of-plane displacement measurements. The system works by constructing a mapping of pixel intensity from reference to the target image(s), where the mapping parameters are identified using a Least Squares approach. In both cases the method implies that a unique intensity pattern exists for each location, thus the surface of the specimen is usually textured artificially, typically by spraying random (black and white) speckles on the surface [1,4]. This works well for engineering or civil engineering objects but is prohibiting in the case of Cultural Heritage Objects. Previous studies have shown that 3D DIC is very useful for monitoring changes in mockups of CHOs e.g. paintings or canvas surfaces at which it is allowed to introduce an artificial texture [5,6]. However, when it comes to original CHOs it is not permitted to apply any artificial texture pattern on the surface of the objects.

Therefore our aim is to test what conditions have to be fulfilled in order to apply DIC method for objects with natural texture and be able to provide high and uniform in total Field-of-View (FoV) accuracy of the results during monitoring of selected cultural heritage objects. During processing, we determine special schemes for the identification of the best DIC parameters including the size of subset and the value of step.

Sample Description

In our experiments we had focused on parchments which are very important group of CHOs. On the other hand they are very sensitive to environmental changes and are characterized by very complex physical structure. In details parchment's structure consists of collagen made up of a sequence of amino acids linked into a polypeptide chain whose spiralling, triple structure quantitatively dominates the molecule [7,11,13]. The presence of amino acids with polar side chains determines the strongly hygroscopic nature of parchment. Parchment's ability for water exchange (hygrometric change) depends on the relative humidity of the environment, but also on the condition of collagen [7]. The aging of parchment affects the contraction of fibres, which is reduced and slower in the dehydration process of older parchment [7,12]. During the course of aging, the structure of parchment becomes more hydrophilic [10,13].

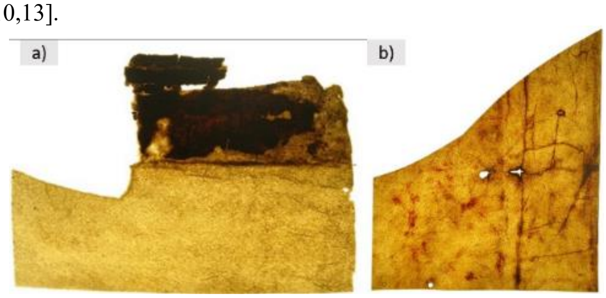

Figure 2: Transmitting light images for samples of parchment with natural texture: a) Historical sample from the XVI century (sample 1) and b) sample with unknown dating (sample 2)

Historical samples used in the study are designated as Sample 1 and Sample 2 (Figure 2). The sample referred to as Sample 1 dates back to the 16th century. It is a fragment of a strip supporting the spine of an old print of *Vita Beatissimi Stanislai Cracoviensis episcopi* by Jan Długosz, manufactured in 1511 Jan Haller's printing house in Kraków. The fragment comes from the documentation accompanying its 2005-2008 conservation. It is a two-sided, calfskin parchment (vellum), irregular in shape (ca. 4.5 x6.5 [cm]). Another fragment of dark leather (2x4.5 [cm]) is glued to the upper part of the sample (Figures 2a and 3), probably as a result of local delamination of the original leather binding (Figure 3a). This is also evidenced by the sample's thickness – the parchment itself is even, ranging between 0.21-0.24mm, and the reinforced part/the thicker section is between 0.56-0.63mm. The natural deformation of the surface indicates that the fibres are positioned parallel to the longer side of the sample. It is not possible to determine the exact section of the animal the material comes from.

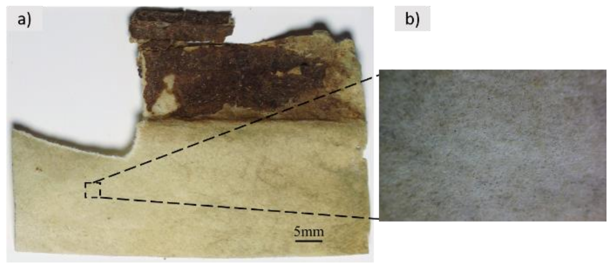

Figure 3: a) image of sample 1 and ;b) Calfskin parchment (vellum), magnification x40

The age of the sample 2 is unknown. The 8x7[cm] fragment probably comes from coloured limp binding, traces of which can be seen on the surface (Figure 4). It is a calfskin parchment (vellum), processed on one side. The thickness of the sample ranges from 0.30 to 0.45 mm. The natural deformation of the surface indicates that the fibres are oriented crosswise to the longer side of the sample. It should be noted that the areas subject to the strongest deformation are the thinnest.

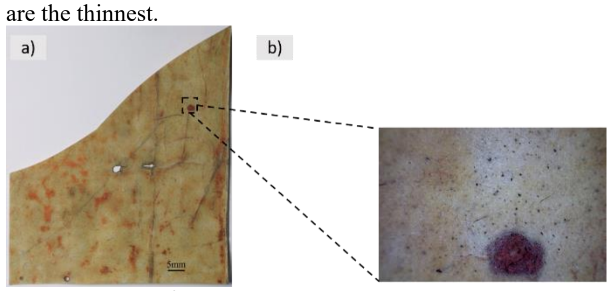

Figure 4: a)Image of sample 2 and b)Follicle pattern and red pigment residue, magnification x40

It is worth remembering that fragments of historical parchments, in addition to additives introduced in the technological process, may contain the remains of a colour layer (Figure 4) or surface coating substances (Figure 3). In this case, it would be advisable to further define the qualitative and quantitative composition of the material (SEM-EDS).

Experimental Apparatus

The experimental apparatus consists of two monochrome cameras (Point Grey model GRAS-50S5M-C) with resolution of 2448x2048 pixels and 16mmobjectives. The cameras were fixed at the aluminium rod with the optical axis crossing at the central point of the FoV under the angle 26.9 deg. The whole 3D DIC system was placed inside a humidity chamber (CTS - Climatic Test Chambers). The total FoV was 30,5cm x 25,0cm and both historical samples were measured simultaneously The lighting (commercial LED stripe) was fixed around the cameras system in order to provide efficient side illumination for the detection of the natural pattern of the sample. Throughout the experiment the temperature inside the chamber was kept constant at 20ºC. The data were captured by the two synchronized cameras using a portable industrial computer equipped with custom made software. The data analysis and data visualization were carried out using Correlated Solutions, Vic-3D 7 [14] software and part of the analysis was done in MATLAB. In the DIC calculations we had used as correlation criteria zero-normalized squared differences [13]. The subset and step parameters selected were 37 and 7 pixels respectively. The selection of the subset and step values is discussed in the next session. Based on the optical system magnification a single pixel in the object plane was representing 0.12 mm distance.

As demonstrated in the literature review [7,13], the aging conditions in the humidity chamber can vary depending on a parchment. According to standards (ISO 2419:2012) a stabilization phase should last a minimum of 24hours, while extending the duration might be beneficial. We assumed humidity fluctuations starting based upon accepted, although disputable [8,9,10], standards: T=(20±2)°C and RH=(50±2)%. This scenario corresponds to the actual fluctuations in museum or archive storage facilities. For the realization of the experiments the RH scenario used to investigate the sample's response is the following:

- increase of RH from 46% to 53% and stabilization for 48h;
- decrease of RH from 53% to 41% and stabilization for 5h;
- decrease of RH from 41% to 38% and stabilization for 5h.

The recording rate was set at 15 seconds during the transition of the RH from one value of percentage to another and at 15 minutes during the stabilization phases.

Results and discussion

Correlation Coefficient

As stated earlier a prerequisite for applying the 3D DIC technique is the existence of a unique speckle pattern on the surface of the sample that will provide the basis for the correlation analysis. A typical speckle pattern is shown in Figure 5a, and corresponds to a parchment mock up at which the artificial texture was added for comparison purposes. Such patterns enable high correlation between the subsets in subsequent images used in DIC technique. Vic-3D computes correlation & displacement uncertainty values and represents them as the variable sigma σ(x,y). The closer sigma is to zero, the more statistically likely the value of calculated displacement is indeed the correct value. High sigma values indicate higher measurement uncertainty, which can result in an increase in noise for shape, displacement, and strain data. Sigma is reported as a standard variable for every test and is defined as the confidence interval for the match at (x,y) point, in pixels. The map of sigma for the given object (FoV) depends on the local quality (randomness and contrast) of its surface texture which to large extend translates into the size of subset chosen for calculations. In the case of artificial, high quality random texture the condition for the minimum size of subset depends on an average size of a speckle – the subset has to contain minimum a few speckles. Typically the sizes of subset ranges from 10 to 20 pixels. In the case of objects with natural texture, usually the subset has to be significantly bigger in order to contain areas which include sufficient contrast and/or information content. Also due to locally low quality content the sigma values may differ significantly within the FoV. For the purposes of this study the minimum subsets that provided acceptable sigma map were determined, namely 35x35 pixels for sample 1 and 31x31 pixels for sample 2. Nevertheless for comparison purposes the maps were calculated for slightly higher and the same for both samples subset value equal to 37x37 pixels. This subset size allows for reasonable analysis (no significant masking areas) for both historical samples during total monitoring experiment. The value of step parameter was chosen for 7 pixels. This is typical value for the resolution of the camera and FoV that we are using and high size of subset, as it is a good selection between the time of calculation and spatial resolution of the displacement maps. To illustrate well the consequences of using artificial and natural texture we present the sigma colormaps obtained for the parchment mock-up with artificial texture (Figure 5) and for samples of historical parchments (Figure 6).

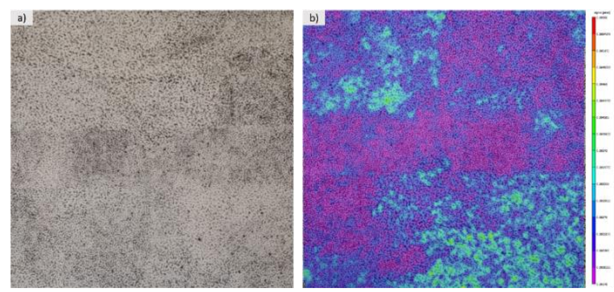

Figure 5: a) Mock up sample of parchment with typical speckle pattern and b) its sigma map P-V=0.0039

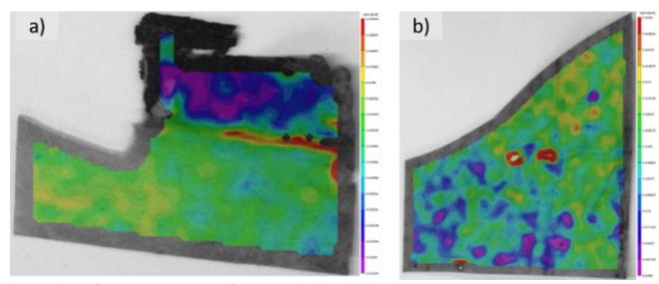

Figure 6: Correlation map for a)sample 1 , P-V= 0.031 and b) sample 2,(Peak to Valley) P-V=0.0391

It can be easily seen that the sigma map of the sample with artificial texture has highly uniform distribution of its values and the low value of P-V =0.00391pixel, which guarantees high accuracy of displacement analysis. The areas with lower and higher σ values can be recognized and correlate with the areas of lower contrast speckles at the image of mock up sample (Figure 5a). The sigma maps obtained for the sample 1 and 2 with natural texture are highly inhomogeneous and their P-V values are approximately 10 times higher than in the case of the mock up sample. We can also see that the areas next to domain discontinuities (holes at sample2) and joint/shadowed areas have very high sigma values. We demonstrate the differences of the sigma maps in the three analyzed cases through the comparison of the histograms of sigma values, their mean values and standard deviations (Figure 7).

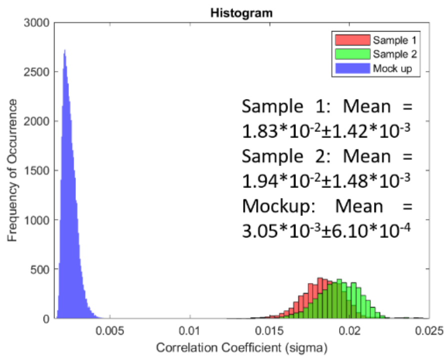

Figure 7:The histogram of correlation coefficient σ for mock up sample with artificial texture and (historical) samples 1 and 2 with natural texture.

The mean value and standard deviation of sigma for mock up sample are a few times lower than those of both samples with natural texture. Knowing that 1pixel=0.12mm in the object plane the uncertainty of the displacement measurement for historical parchment samples is at the level of 1-2μm. Finally the expected accuracy of the displacement measurement is 0.12mm/20=6μm (due to subpixel analysis [1]) increased by the uncertainty of the measurement due to significant σ value. In the case of parchments the expected displacements have the range up to several mm and such accuracy is sufficient for most of the investigations.

Displacements

In this work, we study the response of two historical parchment samples during controlled relative humidity changes. The first quantity to be measured by 3D DIC is the shape of a sample. The examples are presented in Figures 8 and 9), at which the shapes of samples 1 and 2 at the beginning and at the end of the experiment are shown.

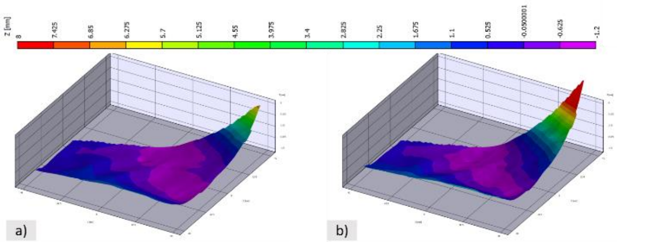

Figure 8: 3D shape plots with the colormap indicating the height values of sample 1: a) at the beginning (P-V= 2.94mm) and b) at the end (P-V=3.06mm .t=58 hours) of the experiment

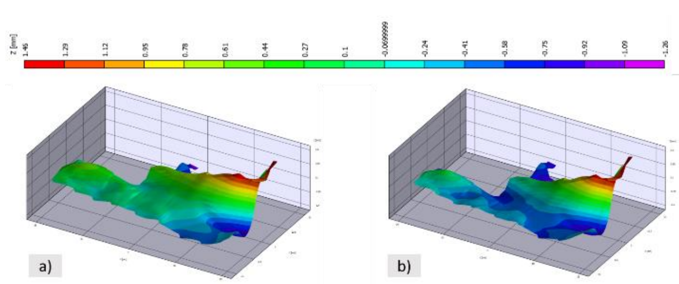

Figure 9: 3D shape with the colormap indicating the height values of sample 2: a) at the beginning (P-V= 5.2 mm)and b) at the end (P-V=9.05mm ,t=58 hours) of the experiment

For sample 1 the main changes in shape are located in the lower part, which has been significantly deformed. Sample 2 exhibits the largest deformations at the edges, one of which has been significantly lifted in comparison to the beginning. However from mechanical and conservation point of view the out-of-plane displacements (deformations) and in-plane displacements (related to strains in an object) are most important quantities. 3D DIC allows to monitor them with the frequency adopted to the speed of the undergoing phenomena. Below at the beginning we present the set of displacements for both historical samples that correspond to a certain time moment at the end of the experiment (t=58 hours), where the RH is 38%. The displacements are represented by 2D colourmap overlayed on the 2D image of the sample. As shown in Figure 10 even the final images of the experiment are analyzed in full domain (no masking) which proves correctness of the selected parameters (subset and step).

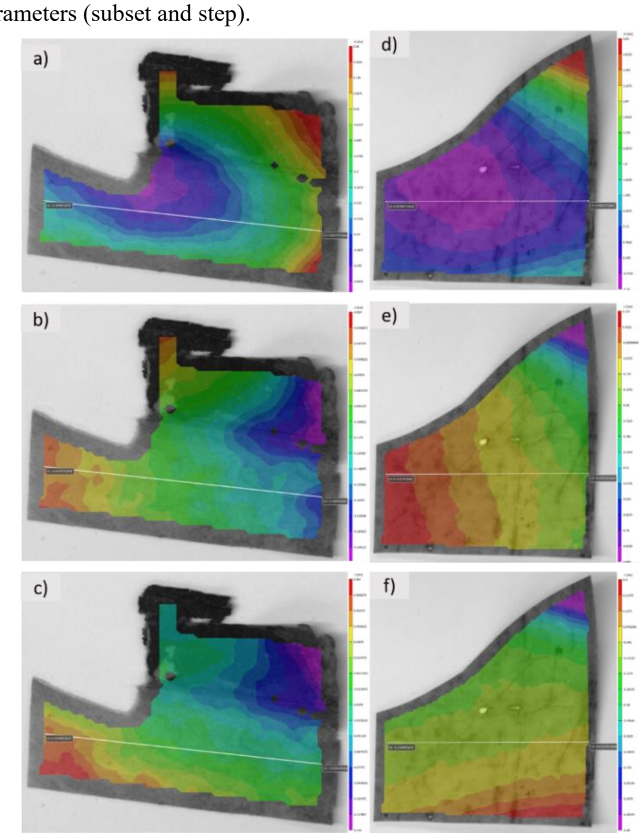

Figure 10: The displacements of sample 1(a-c) and sample 2 (d-f) at the end of experiment (t=58 hours): out of plane (W(x,y)) displacements a) P-V= 0.84mm, b)P-V=4.28mm and in-plane displacements b) U(x,y), P-V= 0.22mm, e) U(x,y), P-V= 1.00 mm c) V(x,y), P-V=0.21 mm and f) V(x,y), P-V= 1.39mm. The white lines shows the location of cross-sections along which the displacement in the function of time are extracted (see Figure 11)

Both samples have undergone significant out-of-plane and in-plane displacements by the end of the experiment. Overall, the displacements of sample 2 (which is bigger and more uniform in thickness) are higher than the displacement of sample 1. Both samples present out-of-plane displacements (W) with negative values in their center and positive at the right hand side corners which have been lifted, with the maximum positive displacement for sample 1 - 1mm and for sample 2 - 3.94 mm (Figure 10a,b). The negative W displacement is higher for sample 1, reaching up to -0.6mm in the lower part, and lower for sample 2 (-0.34mm). In-plane displacements of sample 1 (Figure 10b,c), are relatively small but they indicate big displacement gradient in the region of a joint between the upper and lower part of the sample, so we can expect significant strains in this area. Sample 2 experiences higher in-plane displacements with similar P-V values for U and V (1 and1.4mm, respectively). This supports the information about the sample 2 that the fibres are oriented crosswise to the longer side of the sample. We can have similar discussion for a set of displacements calculated for the reference and actual (sequentially captured) pairs of images.

Sometimes more convenient way to study a local behaviour of the sample in time is to select a cross-section(s) and present the displacements in the form of spatio-temporal map of displacement which is composed of the cross-sections extracted from the numerous set of 2D displacement maps. This visualization method seems to be highly useful for the analysis of results of long monitoring sessions during controlled environmental changes.

In this paper we present the spatio-temporal maps of W, U, V displacements (Figure 11) representing the changes in the selected cross-section marked at the sample 1 (Figure 10a-c) and at the sample 2 (Figure 10d-f). The first change of RH from outside chamber conditions (46%) up to reaching 53% RH inside the chamber is represented by just a few bottom lines indicating rapid increase of in-plane U and V displacements and rapid decrease (sample 1) and inhomogeneous increase (sample 2) of out-of-plane displacement. After 1 hour, the displacements of both samples stop changing (the samples are stabilized). The sample 1 shows higher negative deformations on the left side, for W, and almost equally distributed in-plane displacements. Sample 2 shows positive W displacement on the right side and negative elsewhere, while again the in plane displacements are equally distributed along the selected line. Each next RH change is accompanied by a change in the displacement along the selected cross-section, which confirms that parchment samples reacting to the surrounding humidity fluctuations pretty fast and subsequently undergoes changes in its shape. From Figure 11 we can observe that the major displacements occurred for both samples when the RH percentage decreased to 41%. Once the change in the humidity takes place, the in-plane and out-of-plane displacements are affected. Regarding the W displacement for sample 1, a big decrease is noticed in the middle of the line, right after the RH change which is later released and the displacement returns back to its previous state. At the same time, while the middle part of the line returns to its previous displacement values, the edges are experiencing an increasing trend. The in plane displacements show similar trends with the maximum and minimum detected on the same parts of the analysed line. In sample 2 the RH change to 41% results into a higher W displacement along the edges of the selected lines which is later slightly reduced. The in plane displacements are also affected by the RH decrease, with U gaining both higher and lower values along the selected line and V gradually decreasing along time.

During the last stage of RH changes (decrease from 41% to 38%) we observe increase of the out-of-plane displacements at both sides of sample 1 cross-section, while in sample 2 the values of W-displacement decrease. Also the further significant inhomogeneous changes in in-plane displacements of both samples is observed, which indicate the increase of strains in the parchment material.

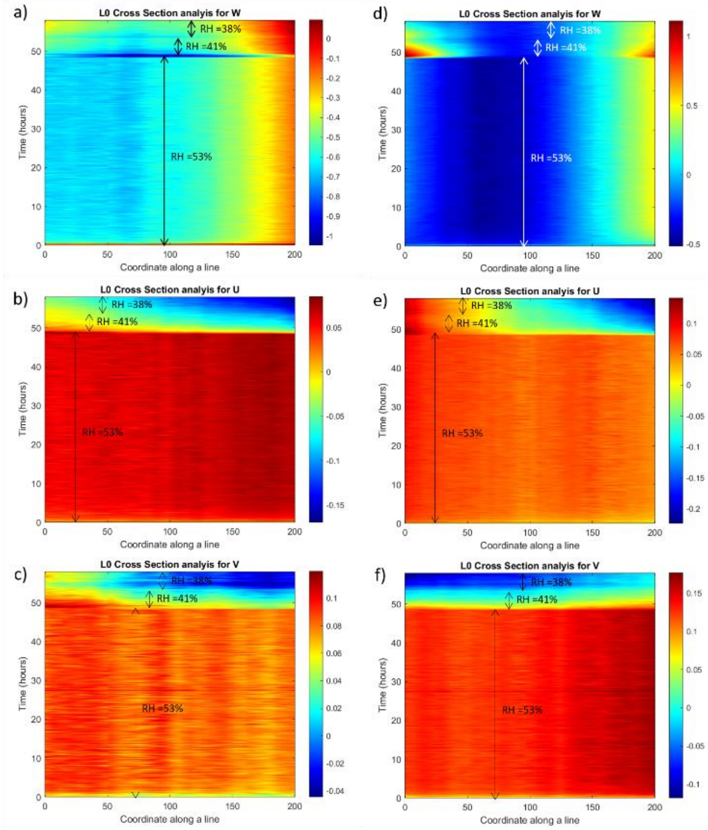

Figure 11: displacement evolution with time along the selected (line)cross section for sample 1 (a-c) and sample 2 (d-f). W- displacement a) and b), U-displacement c) and d), V- displacement e) and f); the RH % is also indicated on each graph

Conclusions and future work

We have successfully measured and monitor displacements induced at the surface of parchment samples under varying humidity levels. Using 3D DIC we were able to record the response of two historical parchment samples for fluctuating RH. This was done by exploiting the natural texture of their surface without applying an artificial speckle pattern. Careful selection of the DIC algorithm parameters allows to analyse the samples in full field of view with sufficiently low measurement uncertainties. Both in-plane and out-of-plane displacements were studied and the response of the samples on the RH changes has been analysed for selected moments during experiment as well as in the function of time. Using 3D DIC it was possible to detect both the global as well as the local behaviour of the sample. Also the spatio-temporal analysis of the selected data cross-sections seems to be very helpful for the analysis of massive data provided by the long term experiment. Due to lack of sufficient space in this manuscript we had not provided the strain analysis which is embedded in 3D DIC investigations, however using the proposed spatio-temporal visualization create great possibilities for strain development monitoring especially in the case of local weakness of the material. Therefore in the future works the full 3D DIC potentials in investigations and monitoring of Cultural Heritage Objects like parchments or canvas paintings should be used.

Referring to historical parchments the future works should focus on the studies conducted in a wider range of RH with the aim to determine the humidity changes that significantly aid to the deformation of parchment samples. Another aspect that can be investigated is the influence and evaluation of different mechanical stabilization conditions, as well as, temperature variations. When it comes to expanding the scope of the study, it would be reasonable to supplement the research also with a thorough analysis of historical material with the use of modern methods (such as DSC, FTIR, HPLC, or SEM-EDS), which would allow us to infer about the parchment itself. To conclude with, 3D DIC has significant potential as tool in the hands of conservation scientists and can be effectively used for the monitoring of cultural heritage objects as well as the development of protocols that will ensure the safety of the object.

Acknowledgements

This work is carried out at the beneficiary partner of CHANGE: Cultural Heritage Analysis for New Generation, Warsaw University of Technology, Poland, received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 813789. The financial support through the project granted by the Scientific Council of the Discipline Automatic, Electronics and Electrical Engineering, WUT is greatly appreciated. Prof. Izabela Zając is acknowledged for providing samples of historic parchments.

References

[1] M. Sutton M, J-J. Orteu, H. Schreier, Image correlation for shape, motion and deformation measurements. Basic concepts, theory and applications, Springer New-York, 2009.

[2] N. Duqueyroix, L. Robinet, C. Barbe, "Expandable Polyester Hinges for Parchment Mounting Performance in Fluctuating Environmental Conditions", Journal of Paper Conservation, vol. 16, no 1,pp. 18–28, 2015.

[3] B. Pan, "Recent Progress in Digital Image Correlation", Exp Mech vol 51, pp. 1223–1235, 2011.

[4] M. Malesa, K. Malowany, U. Tomczak, B. Siwek, M. Kujawińska, A. Siemińska-Lewandowska, "Application of 3D digital image correlation in maintenance and process control in industry", Computers in Industry, vol. 64, no 9,pp. 1301-1315, 2013

[5] M. Malesa, K. Malowany, L. Tymińska-Widmer, E. Kwiatkowska, M. Kujawńska, B. Rouba, et al., "Application of digital image correlation (DIC) for tracking deformations of paintings on canvas", in Proc. SPIE 8084, O3A: Optics for Arts, Architecture, and Archaeology III, 2011.

[6] K. Malowany, L. Tymińska-Widmer, M. Malesa, M. Kujawińska, P. Targowski, & B. Rouba, "Application of 3D digital image correlation to track displacements and strains of canvas paintings exposed to relative humidity changes," Appl. Opt., vol 53, no 9, pp. 1739-1749, 2014

[7] W. Liszewska, New methods of leafcasting in the conservation of historic parchments, Polish Institute of World Art Studies / Academy of Fine Arts in Warsaw, 2017

[8] E. F. Hansen, S. N. Lee, H. Sobel "The Effects of Relative Humidity on Some Physical Properties of Modern Vellum: Implications for the Optimum Relative Humidity for the Display and Storage of Parchment", Journal of the American Institute for Conservation, vol. 31, no. 3, pp. 325-342, 1992

[9] E. Badea, W.Vetter, I. Petroviciu, C. Carsote, L. Miu, M. Schreiner, G. Della Gatta, Giuseppe, "How parchment responds to temperature and relative humidity: a combined micro DSC, MHT, SEM and ATR-FTIR study", Proc. of the 4th International Conference on Advanced Materials and Systems, ICAMS 2012.

[10] L. G. Gonzalez, T. J. Wess, "The effects of hydration on the collagen and gelatine phases within parchment artefacts", Heritage Science, vol. 1, no. 14, 2013

[11] C. J. Kennedy, T. J. Wess, "The structure of collagen within parchment – a review", Restaurator, vol. 24, no 2, pp. 61-80, 2008

[12] D. Bowden, P. Brimblecombe, "Thermal Response of Parchment and Leather to Relative Humidity Changes", Microanalysis of Parchment, pp. 63-72, 2002.

[13] C. M. Popescu, C. A.S. Hill, C. Kennedy, "Variation in the sorption properties of historic parchment evaluated by dynamic water vapour sorption", Journal of Cultural Heritage, vol. 17, pp. 87-94, 2016

[14] Correlated solutions, Vic-3D 7 Reference Manual (2016).

Author Biography

Athanasia Papanikolaou received her master's in Photonics and Nanoelectronics from the University of Crete. Currently she is a PhD Candidate at Warsaw University of Technology and a Marie Curie ITN fellow at the EU project CHANGE. Her work is focused on the development of a portable multimodal device for surface analysis and monitoring of cultural heritage objects.

Dorota Dzik-Kruszelnicka holds a PhD Degree in conservation. She has been working at the Department of Book and Paper Conservation, Faculty of Conservation and Restoration of Works of Art, Academy of Fine Arts in Warsaw since 2010 and as a conservator at the National Museum in Warsaw since 2007. She has been involved in several conservation and research projects and is the author of many publications on paper conservation.

Sunita Saha received her master's degree in computer science and engineering from NERIST (2018). She is currently making her doctoral studies at the Faculty of Mechatronics Warsaw University of Technology. Also, a Marie Curie ITN fellow (ESR4) at the EU project CHANGE. Her works focus on the Analysis and visualization of multi-modal image data in CH surface monitoring over time or before and after the restoration process.

Malgorzata Kujawinska PhD DSc., SPIE Fellow, Full Professor of applied optics at Warsaw University of Technology. International expert in full-field optical metrology, development of novel photonics measurement systems, 3D quantitative imaging in engineering, cultural heritage and biomedical engineering. Author of one monograph, several book chapters and more than 250 papers in international scientific journals. The recipient of SPIE 2013 Chandra S. Vikram Award in Optical Metrology.