Progress in strain monitoring of tapestries

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Abstract

This paper reports interdisciplinary research between conservators and engineers designed to enhance the long-term conservation of tapestries (tapestry-weave hangings) on long-term display. The aim is to monitor, measure and document the strain experienced by different areas of a tapestry while it is hanging on display. Initial research has established that damage can be identified in the early stages of its inception, i.e., before it is visible to the naked eye. The paper also reports initial results of strain data visualisation that allows curators and conservators to examine how strain develops, thereby facilitating predictions about the changes in the form or condition of the tapestry. Strain data visualisation also allows the strain process to be recorded, thereby facilitating the effective documentation of display methods and conservation interventions. The paper reports the use of point measurements (using silica optical fibre sensors) and full-field monitoring (using 3-D photogrammetry with digital image correlation (DIC)).

Résumé

Cet article traite des recherches interdisciplinaires menées par les conservateurs-restaurateurs et les ingénieurs pour améliorer la conservation-restauration à long terme des tapisseries (tapisseries murales tissées) exposées sur une longue durée. L'objectif est de surveiller, mesurer et documenter les tractions subies par les différentes parties d'une tapisserie alors qu'elle est accrochée au mur. Les premières recherches ont établi que les dommages peuvent être identifiés dès leur apparition, c'est-à-dire avant qu'ils ne soient visibles à l'œil nu. L'article montre aussi les premiers résultats de visualisation des données de traction, ce qui permet aux conservateurs et aux conservateurs-restaurateurs d'observer comment se développent les tractions et de prévoir ainsi plus facilement les modifications que subit la tapisserie au niveau de sa forme ou de son état. La visualisation des données de traction permet aussi de documenter le processus de traction, et par conséquent de faciliter la documentation des méthodes d'exposition et des interventions de conservation-restauration. L'article rapporte l'utilisation des mesures ponctuelles

Keywords

textile conservation, tapestry, condition monitoring, engineering, strain, optical fibre sensor, 3-D photogrammetry, digital image correlation (DIC)

Introduction

Tapestries are an important feature of many historic house and museum collections. They are often displayed on walls as originally intended, either hanging from the top edge or attached around all four edges.

Textile conservators are experienced in visually assessing textiles for evidence of damage. Condition assessment by visual inspection is now routine (Lennard 2006). However, such visual inspection does not allow quantification of the strain imposed by the textile's own weight. Tapestries, like other textiles, experience deformation under load which is presumed to be a significant factor in their deterioration. Although there has been some interesting work (Bilson *et al.* 1997), this aspect of textile conservation has not been much investigated. The monitoring of deformation under a constant load is common in engineering, where it is quantified in terms of an engineering metric known as mechanical strain. Applying strain-based techniques to the monitoring of damage caused by hanging tapestries would enable areas of degradation to be identified before it is apparent that damage is occurring, i.e., before it is visible to the naked eye.

The research programme seeks to answer the following questions:

- How can the strain imposed on different areas of a tapestry be quantified?
- How can areas at risk of imminent damage in a historic tapestry be identified before the damage is visible?
- How can the data be presented in a form that is accessible to conservators and curators to aid informed decision-making?

Answering these questions will aid conservation decision-making, by showing which tapestries in a collection, and which areas in a tapestry, are at greatest risk of damage through strain. This will help to prioritise conservation interventions.

Engineering methodologies have been widely applied in the cultural heritage sector (e.g., Spagnolo *et al.* 2000, 2003; Falciai *et al.* 2003; Dulieu-Barton *et al.* 2005). Recent examples include work by C Young of the Courtauld Institute of Art, UK (1998, 1999). Their application to historic textiles is uncommon. A notable exception is the investigation of St. Francis of Assisi's cloak by researchers at the *Opificio delle Pietre Dure e Laboratori di Restauro* in Italy (Varoli-Piazza and Rosicarello 1996).

(en utilisant les détecteurs à fibres optiques de silice) et la surveillance plein champ (en utilisant la photogrammétrie 3D avec la corrélation d'image numérique).

Synopsis

Este artículo presenta una investigación interdisciplinaria entre conservadores e ingenieros diseñada para mejorar la conservación a largo plazo de tapices (tapices tejido colgantes) en exhibiciones largas. El objetivo es monitorear, medir y documentar los efectos de la tensión (distensión?) en las distintas zonas de un tapiz al estar colgado para su exposición. La investigación inicial permitió establecer que los daños pueden identificarse en las fases iniciales, es decir, antes de ser visible a simple vista. El artículo presenta también los resultados iniciales de la visualización de los datos sobre los efectos de la tensión, que permite a curadores y conservadores analizar cómo avanzan los efectos de la tensión, facilitando de este modo las predicciones sobre los cambios en la forma o en el estado del tapiz. La visualización de datos sobre strain también permite que se registre el proceso de su evolución, facilitando así documentación eficaz de los métodos de exposición y de las intervenciones de conservación. El artículo presenta el uso de mediciones puntuales (empleando sensores de fibra óptica de sílice) y un control de campo completo (empleando fotogrametría en 3-D con correlación de imagen digital (DIC)).

Tapestry monitoring

This paper reports work by an interdisciplinary research team, established at the University of Southampton (Southampton, UK) in 2002, consisting of two researchers each from the Textile Conservation Centre (TCC) and the School of Engineering Sciences (SES). With post-doctoral research assistants and students, the team investigated a number of possible techniques for monitoring tapestries and confirmed the feasibility of using engineering techniques for damage assessment of historic tapestries (Sahin *et al.* 2006; Dulieu-Barton *et al.* 2007a, b)[1]. The pilot study also included some computer modelling of the effects of different patching fabrics and hanging methods (Coulter 2007).

The pilot study investigated the mechanical behaviour of a representative material, a tapestry-like wool fabric, and showed that the material behaves in a predictable fashion and can be monitored using engineering techniques. This allows samples to be tested to destruction, enabling greater understanding of damage mechanisms and informing the relationship between the damage and applied load. The work examined contact and non-contact techniques, including optical fibre strain gauges, Electronic Speckle Pattern Shearing Interferometry (ESPSI), thermography and photoelasticity (Dulieu-Barton *et al.* 2007). The main conclusion of the pilot study was that a hybrid approach is required that combines point measurements from local reference sensors integrated with long-term full-field assessment. Full-field assessment would provide information about the deformation of the whole tapestry while local reference sensors would provide quantitive strain data in the monitored areas and act as a reference to calibrate the data from the full-field technique. Integration of both sets of data would allow the creation of strain maps which correlate the images of overall deformation with the numerical strain data.

The main aim of this paper is to report initial results from a follow-up three-year research programme which started in January 2007[2]. The results of the pilot study identified that optical fibre sensors appeared to be the most suitable for the local monitoring device, and that 3-D photogrammetry using digital image correlation was the most suitable for the full-field monitoring. This research aims to develop these techniques.

Point measurement

Local monitoring devices attached to the tapestry must be invisible to the viewer and must not accelerate the degradation of the tapestry. Optical fibre sensors met these criteria: Oddy tests indicated that the tested optical fibres can be attached to tapestries without long-term risk (Paul 2007).

For an optical fibre to respond to the strain in a tapestry it must be fixed to the tapestry along the length of the sensing element in the optical fibre; the characteristics of the sensing element change with the change in strain in the tapestry and allow a measurements to be taken. The quality of the measurement depends on the effectiveness of the strain transfer between the tapestry and the sensor, which is determined by the bond between the sensor and the tapestry. Methods of attaching the optical fibres have been tested on sample material by, for example, weaving, stitching and bonding them with an adhesive. The samples were subjected to a quasi static strain and the response of the Bragg gratings sensor was evaluated. In the tests, the applied strain was in the region of 2 to 3 per cent, i.e., in the operational range of the sensors. Previous mechanical testing shows that this is the region where the damage in the tapestry is initiated and is not apparent in visual inspections.

Two problems were identified with the use of optical fibre sensors. First, none of the methods of attachment gave satisfactory strain transfer, although of the three, bonding was the most effective. Second, silica optical fibres have a much greater Young's modulus than wool, causing stiffening of the sample material in the vicinity of the sensors, and potentially affecting its response to the strain. The experiments will be repeated with polymer optical fibres which are less stiff and more elastic, and have a Young's modulus closer to that of wool, but the technology of polymer optical fibre sensing is currently less advanced as there is insufficient light transmission to make viable measurements.

Full-field approach

Covering a tapestry in an array of optical fibre sensors would be time-consuming, costly and disfiguring and so a non-contact means of monitoring the entire tapestry is required. One criterion for the full-field monitoring was that the equipment should be easily transported and installed in a historic house with the minimum of intrusion. 3-D photogrammetry was identified as the most suitable technique. To process the data obtained for the photogrammetry and obtain full field deformation maps digital image correlation is used. Digital image correlation is used by engineers for testing structures, but the technique is not believed to have been used previously for monitoring historic textiles. This technique is based on the principle of photographing the same area of an artefact using two digital cameras simultaneously; the cameras are set some distance from each other. This produces two slightly different images of the same area which allows a 3-D deformation pattern to be produced (as shown at the top of Figure 1).

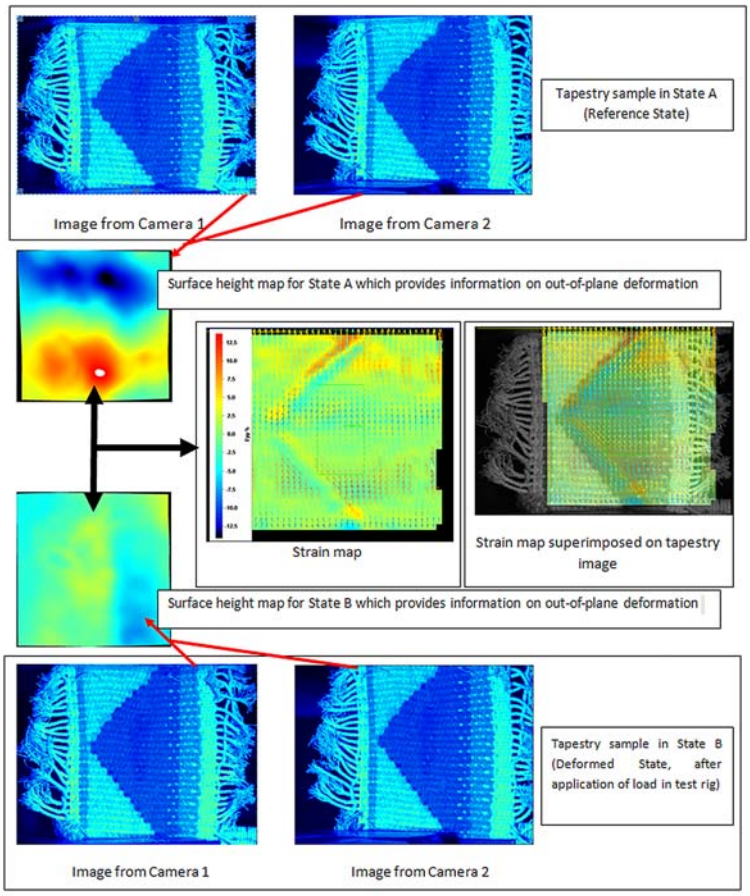

Figure 1. A representation of full-field monitoring of a tapestry weave sample by 3-D photogrammetry with digital image correlation

Figure 1 illustrates how the technique works. Two pairs of images are obtained with the artefact in different states; these are correlated to provide information on both in-plane and out-of plane deformations. The different states could be, for example, with a tapestry lying flat and then hanging; or a measurement could be taken with a tapestry hanging on display, and then repeated a year or ten years later. In the tapestry sample illustrated in Figure 1, the different states are before and after the application of a load. Specific points on the images are compared and a measurement of the deformation can be obtained. The difference in strain between the two states can then be calculated and mapped, shown on the strain map in the centre of Figure 1. This clearly shows higher levels of strain along the diagonal lines where different colours join, as might have been predicted. In digital image correlation this process is carried out automatically over the entire field of view, providing full-field representation of the deformation.

Research to date confirms that this full-field technique is very promising. A map of the strain is produced allowing areas of tension and compression, which are not evident to the naked eye, to be clearly visible. In this part of the research data presentation and interpretation are key issues. Digital image correlation allows a full-field strain image to be superimposed on an image of a tapestry (shown at the centre-right of Figure 1). In this way the data can be visualised to allow informed discussion about a tapestry's condition and a more accurate prediction of likely further damage.

Hybrid approach

When the two techniques are working well, they will be tested together on a larger scale, on a purpose-woven tapestry. The local sensor will be integrated into the tapestry as it is constructed. The tapestry will be placed in a custom-designed loading rig that allows accelerated deformation under constant artificial load to the point of destruction. The aim of this is to model the entire load-bearing life of the tapestry in a few months, from new to inability to continue hanging. Photogrammetry data will be collected on a regular, probably daily, basis, with the aim of gaining an equivalent amount of information as from a tapestry hanging on display for many years. This will help to refine the point measurement and full-field techniques.

Finally the hybrid monitoring system will be tested on a second, custom-woven tapestry and also on a historic tapestry in a historic house. As the monitoring will take place at intervals using mobile equipment, it will be necessary to identify exactly the same area of the tapestry to obtain the next image in the series. Locating the same area is normally achieved by superimposing a speckle pattern onto an artifact, but from the preliminary tests it is expected that the tapestry pattern will provide its own means of recognition. The integral sensors will monitor the tapestry's response to environmental conditions as well as providing a reference for the strain measurement. The monitoring will "produce 'real' data from a 'real' object", the objective of a previous experiment (Howell 1996: 696). The *in-situ* monitoring will take place on a historic tapestry belonging to English Heritage, the National Trust or Historic Royal Palaces, heritage organisations in the UK.

Conclusion

This research has already shown that the strain imposed on different areas of a tapestry sample can be quantified and that areas at risk of imminent damage in a historic tapestry can be identified before the damage is visible. The image correlation technique has the potential to be a very effective means of presenting this information in a form that is accessible to conservators and curators to aid informed decision-making. It will also provide a mechanism for informing the public about the processes of preventive and remedial conservation.

In the long term it is intended that the hybrid approach will allow comparative study of different conservation interventions, e.g., different types of conservation stitching and lining. This hybrid approach could also be applied to different types of textiles, e.g., flags and banners, as well as other types of objects. The research demonstrates mutually beneficial and effective interdisciplinary research collaboration between conservators and engineers.

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Notes

1 This project complements a three-year EU-funded project, Monitoring of Damage to Historic Tapestries (MODHT) which focused on the characterisation of chemical changes in historic tapestries (Hallett 2006).

2 UK Arts and Humanities Research Council funded project (AHRC Research Grant award AH/D001404/1).

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Equipment

Digital Image Correlation system
3D DIC StrainMaster System
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