AUTOMATIC DETECTION OF COLLAGEN FIBRES SHRINKAGE ACTIVITY USING Σ-Δ FILTERING

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The thermally-induced structural collapse of collagen fibres in collagen-based historical materials and artefacts such as leather, parchment and skin is currently measured through the Micro Hot Table (MHT) method. This method, widely used in conservation-restoration for characterising historical materials' deterioration, is based on a combined thermal and microscopic technique which evaluates the motion behaviour of the collagen fibres dispersed in aqueous milieu and heated at 2°C·min inside a thermostatically controlled heating cell. The collagen fibre motion observed by a stereomicroscope and digitally-recorded with a camera is called shrinkage activity and has been defined by a sequence of five temperature intervals. The intrinsic main limitations of this method, i.e. time consuming and human eye assessment variability causing high errors and making it impossible the inter-laboratory comparison, can be overcome by the use of image processing techniques for the automatic detection of shrinkage intervals. An improved MHT method incorporating image analysis will deliver a really objective and faster analytical technique and enable for effective diagnosis and conservation decision in museums, archives, libraries, public and private galleries.

Keywords: historical parchment and leather, shrinkage, Σ-Δ filtering

INTRODUCTION

In intact fibres, the helical structure of collagen with the twisting of micro fibrils and minor fibres is easily visible at microscope. During ageing and deterioration, fibres usually evolve through flattening, splitting and/or fraying which lead to fragmentation and end by formation ofa gel-like substance that melts by contact with water or even in a very moist environment. In some cases the end product is represented by small hard fragments that do not react any longer by contact with water even on heating. The vital importance of collagen as a biomaterial for documents and artefacts demands a manifold of essential characteristics such as thermal stability, and mechanical strength. These properties are derived from the fundamental structural unit of collagen, the triple helix. The thermal stability can be evaluated by inducing the collapse of the triple helix by progressive, controlled heating. In fact, when progressively heated in water, the collagen triple-helical structure converts to random coil disordered structures over a defined temperature interval which characterises its thermal stability. This process is called thermal denaturation and its macroscopic manifestation can be observed through a stereomicroscope as the shrinkage motion of the collagen fibres. Collagen shrinkage activity associated with thermal denaturation has been defined as a sequence of five temperature intervals (Larsen *et al.*, 2002):

no activity – A_1– B_1– C – B_2– A_2– complete shrinkage (Figure 1)

In the first two intervals, A_1 and B_1, shrinkage discretely occurs in individual fibres and displays higher activity (namely higher amount of shrinkage per unit of time) in B_1 interval. Then, the majority of the fibre mass shrinks in the main interval C. The starting temperature of this interval is the shrinkage temperature, T_s. Generally, the shrinkage activity levels off through B_2 and A_2 intervals. T_f is the temperature at which the very first motion is observed and T_l the temperature of the very last observed motion. While the shrinkage of collagen fibres from new materials runs through all these intervals, for some historical materials neither of these last two intervals has been observed. In some cases the main shrinkage interval C was even absents illustrated in Figure 1 (ASTO 2.1).

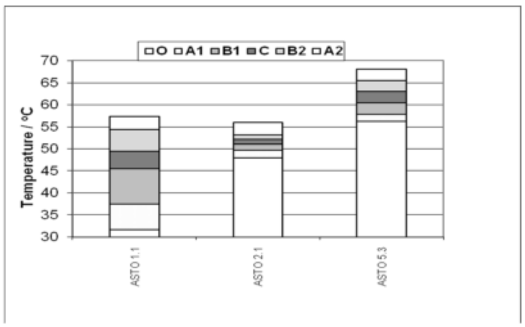

Figure 1. Bar diagram displaying shrinkage intervals for three parchment rolls from the State Archives of Turin (*Le Castellanie* Collection, XIV – XVI century)

The MHT method was established and then improved in the compass of four European projects, STEP (TS967-S82-1994), ENVIRONMENT (EV5V-CT94-0514), MAP (SMT4-96-2101) and IDAP (EVK-CT-2001-00061), in which the end-users have played an active role. The success and the extensive use of the MHT method rely on one hand in its micro-destructiveness (only few corium fibres are required) and on the other hand on the easy interpretation of the results (the more deteriorated the sample fibres are, the lower the T_s). In addition, the simple, easy-to-use and inexpensive equipment composed of a stereo microscope with a camera and a thermostatically controlled heating cell, has certainly contributed to the proliferation of the method in the conservation laboratories across Europe, USA and Canada. Provided that the assignment of the various temperatures to A, B and C intervals is not made in real time but during subsequent observations, the precision of the method may be as good as 0.1 °C while the accuracy was claimed to be 2 °C (Larsen, 2000).The other side of the coin is that, as a simple test of shrinkage temperature measurement, the MHT method has some limitations: (i) low ratio of information obtained over the level of destruction, (ii) lack of detail, (iii) risk of error in the evaluation of deterioration. Correlation with complementary analytical techniques (Badea *et al.*, 2008; Badea *et al.*, 2012b; Mühlen Axelsson *et al.*, 2012; Možir *et al.*, 2012) as well as identification of further shrinkage parameters which well correlate with both the level and type of deterioration such as T_f and T_l temperatures, C and A_2 intervals length, as well as the total shrinkage interval length enables a much more detailed and reliable evaluation of deterioration (Badea *et al.*, 2012a). Furthermore, by analysing the results of the observations obtained by different operators on the same samples, a significant error due to the human factor has been detected, hindering the ability of inter-laboratory comparison. The average duration of a measurement of about 45-60 min adds a further limitation in terms of the high human resources involvement required by the campaigns of damage assessment of large collections. A technological improvement is thus necessary for delivering a truly objective and in-real time analytical technique.

Σ-Δ FILTERING METHOD

The Σ-Δ filter was used for the automatic detection of the shrinkage temperature of collagen fibres obtained by using the MHT method. Most background estimation techniques use only the difference between grey scale values for considering changes in the illumination (Atkociunas *et al.*, 2005). The process of changing the grey scale values in a background image sequence is described as a signal processing system for each pixel. The Σ-Δ filter is used for the nonparametric motion estimation and can adapt very quickly to illumination variations. The key feature of this method is the robustness given by the nonlinearity of the recursive mean compared with the recursive linear mean that is more computational efficient (Manzanera and Richefeu, 2007).

The Σ-Δ background estimation is a simple and efficient method to detect pixels that substantially change in the static scene, considering a time constant that depends on the number of grey levels. It is a temporal processing that can only offer detection at pixel level.

The Σ-Δ background estimation algorithm was tested on a set of 38 image sequences obtained by MHT method for artificially aged leather samples. The values of shrinkage temperature T_s estimated by the human specialist and by using the Σ-Δ algorithm are shown in Figure 2. Similar results were reported for new and historical parchments (Badea *et al.*, 2013).

The mean absolute error of T_s approximated by the use of the Σ-Δ filter is 1.8°C, less than the accepted error in the case of the traditional MHT analysis, i.e. 2 °C.

A further improvement is represented by the automatic detection of all the shrinkage intervals that is in progress within the COLLAGE project. Such a comprehensive profiling of shrinkage activity can support improved preventive care and conservation treatment of parchment and leather collections. The dramatic reduction of the time required for a measurement and increase of the reproducibility of results will help to introduce MHT as a routine evaluation test in preventive conservation practice.

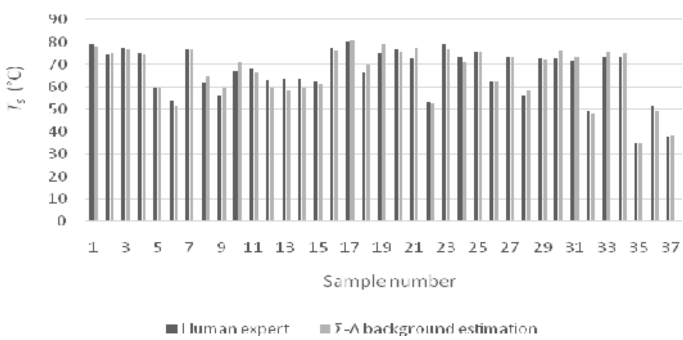

Figure 2. Comparison between the T_s values measured by the human expert and by using the Σ-Δ background estimation algorithm for 38 artificially aged leathers

CONCLUSION

An automatic method for the reproducible and rapid estimation of the shrinkage temperature *T*s of collagen fibres has been developed and tested for a number of leather and parchment objects. The employment of the automated MHT method offers the advantage of providing information on specific alterations at surface and on sample mass, as well as at fibre levelorganisation and thus prevent partial, improper evaluations made by traditional visual assessment.

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