David Mills, Antoinette Curtis, Graham Davis, Paul Rosin, Yu-kan Lai

Peer-Reviewed

Apocalypto

Revealing the Bressingham Roll

'Can modern imaging and image processing techniques retrieve textual content from damaged parchment rolls?'

The Institute of Dentistry at Queen Mary University of London is the leading centre for very high contrast X-Ray Microtomography imaging. The Apocalypto (Greek for Revelation) Project is our collaboration with experts in Computer Vision systems in the Computer Science department at Cardiff University. This collaboration has developed techniques and a workflow that allows us to reveal some textual content from damaged parchment rolls.

In initial results we have produced a virtual unrolling of the full length of the left-hand third of a fused parchment roll, amounting to in excess of 50 lines of text—a five-fold increase over that accessable by traditional means. We expect more complete unrolling as data processing techniques improve.

We think this article will conclusively show that we can apply our techniques to heritage objects and produce information of value to the conservation and archivist communities.

Introduction

The Norfolk Record Office (NRO) holds one of the largest and richest collections of archives in the UK. One of the glories of this Collection is the medieval records it contains; the majority of which are on parchment. These include records from Norwich Cathedral, the boroughs of Norwich, King's Lynn and Great Yarmouth, and the records of the Great Hospital, Norwich. The significance of the latter is recognised by its inscription in the UNESCO Memory of the World Register.

Another important set of documents, which includes a large quantity of parchment, are the thousands of manorial records at the NRO. These have been the subject of a great deal of work in recent years: cataloguing projects have greatly improved access; education has encouraged people to use this rich resource and helped people develop the skills needed to use this sometimes difficult resource; and conservation work has helped repair and make previously inaccessible documents available in the searchroom.

The ongoing work to make more parchment items available has encouraged conservators and scientists to work together to better understand the complex nature of parchment. One consequence of this increased understanding is that many traditional methods of conservation treatment are now being questioned. This poses a significant challenge for conservators and has resulted in a trend of minimal intervention in conservation treatments.

In turn, this has prompted consideration of alternative means of access. Building on the digitisation of original items, and with the support of science, we are now able to explore new means of access through collaboration between heritage, science and technology. With the use of new X-ray technology, we have recently been able to access information from the Bressingham roll, in the form of virtual unrolling.

The Document

History of the Document

The parchment manuscript is an account roll from the manor of Bressingham, dated 1408-9 (NRO, PHI 468/5). The manor of Bressingham lies within the village of the same name on the southern edge of the county of Norfolk. It is on the north bank of the river Waveney three miles west of the market town of Diss. The Pilkington family owned the manor in the early fifteenth century: they had acquired it from its previous owners, the Verdons, when Sir John Pilkington married Margaret Verdon in 1399. The Pilkingtons owned about 20 other manors as well.

1 The Bressingham Roll (NRO, PHI 468/5) overview.

A manor was a source of income for its lord: his income and expenditure is recorded on the annual roll drawn up by his-bailiff or steward. The manor itself was rented out for GBP 24 a year. Other sources of income, recorded on the roll, included profits from holding the manor court, sales of underwood (used for fuel), and leasing out the fishing rights: fish was a very important element in the medieval diet, as the church forbade the eating of meat on many days in the year.

Description and Condition of the Parchment Roll

The parchment roll was identified for possible conservation treatment during stocktaking of collections in December 2005. Comments from the request form for conservation mentioned the parchment roll as being 'stuck together'.

The roll, which consists of one parchment membrane, is of small proportions (Fig 1). The width of the roll measures approximately 270 mm. The total length of the roll is unknown, as it is impossible to unroll completely: at approximately 100 mm from start of the document, the roll becomes fused together (Fig 2). The fusing of the roll is most likely to have been caused by damp storage before the roll was deposited with NRO. This fusion was the main concern, as any future attempts to access more text could cause delamination of the surface of the parchment.

The visible part of the roll shows very obvious evidence of damage with some limited amounts of loss, small tears and some staining. One small area does exhibit an unusual clean-edged circular area of loss and a small tear; reasons for this are unknown (Fig 3). The roll had become crushed from past storage, causing folds across the width in several places.

The parchment has an approximate average thickness of 0.16 mm, giving in places a transparent look to the skin. The skin is thin and, despite being relatively stiff and hard, it is sufficiently flexible to unroll. The surface of the skin is quite polished in places, with evidence of small creases. There are several areas of the skin, which have become scuffed and delaminated. This type of damage suggests that there may have previous attempts to open out the roll once the roll had become fused together.

The main text of the manuscript was found after testing to be written with iron gall ink, written on the flesh side of the skin and appeared to be quite stable. There were only small annotations on the verso.

Treatment Options

Due to the complex nature of parchment, there are many considerations, which have to be taken into account before determining a treatment plan. The initial options appeared to be:

1. repackage and to mark 'unfit for production', noting that the item is fused together and any attempts of unrolling may cause further damage; or
2. attempt to unroll the parchment by using an interventive treatment: if successful proceed with repairs to any damaged areas.

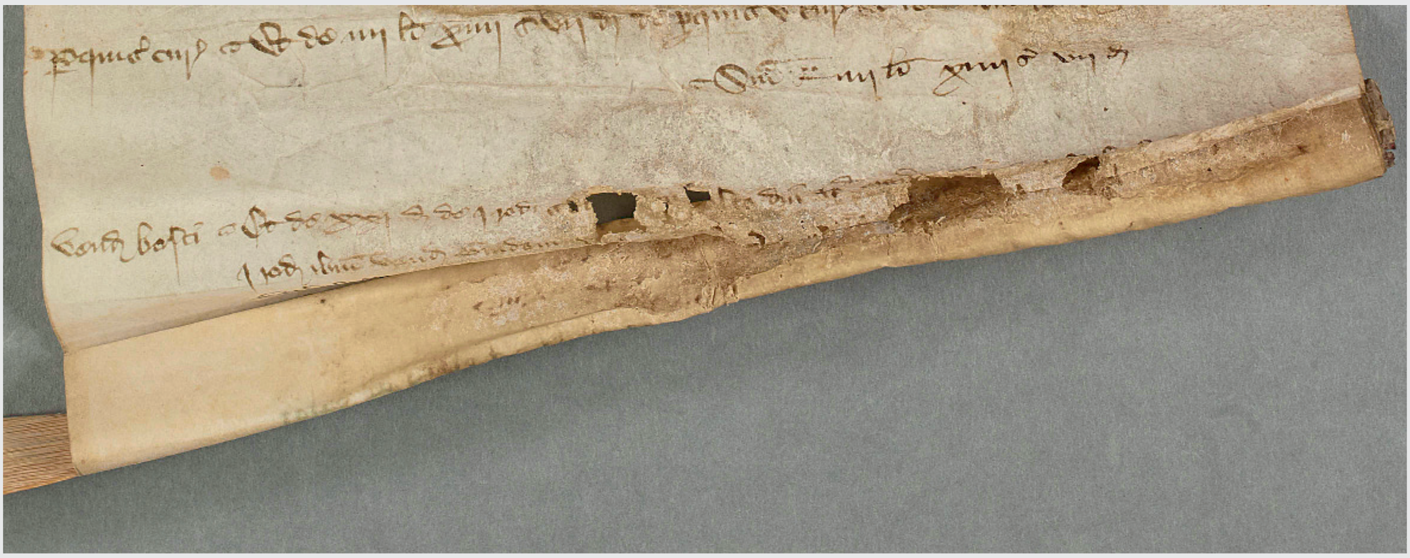
After close examination of the item, it was decided to attempt to release a small area of the fused skin, to test the viability of option 2 above. Such testing would reveal the extent of the fusion: a visual examination of the document suggested that only part of the document was fused.

One of the first considerations was to keep any moisture introduced to a minimum (Larsen et al. 2011). Parchment is primarily composed of collagen and is highly sensitive to water (Gonzalez and Wess 2013). To limit the amount of water used at this stage, an aqueous isopropanol solution (4:1 v/v = isopropanol: de-ionised water) was applied to a very small, restricted area of the parchment.

Unfortunately, the results were poor and could only be improved through the use of a large amount of the solution: the extent of the fusion was considerable and would require extensive treatment. Noting the concerns in the literature (Gonzalez et al. 2012) about the permanent structural changes within the parchment when using such a solution, it was decided to not continue with this type of interventive treatment. The preferred treatment option was therefore for roll to remain as found, as any further interventive treatments would subject the roll to unacceptable risks.

Another Way Forward

When the document was identified for possible conservation treatment, the purpose was to make the document accessible. As



2 Fused section of the roll.

our investigations proved that it would be detrimental to the item to physically unroll it, other non-interventive options were investigated, including X-ray microtomography scanning and virtual unrolling.

The Scannning

The Technique

X-ray microtomography (XMT or micro-CT) is a miniaturised version of medical human body CT scanning (Elliott and Dover 1982), designed to look at specimens much smaller than the human body, with a resolution in the region of microns. The high contrast, high dynamic range XMT scanners developed in recent years at Queen Mary University of London (QMUL) (Davis et al. 1997; 2003, 2012) allow the imaging of the small differences in X-ray absorption between inks and the material they are deposited upon (paper, parchment, etc.) (Mills et al. 2012). As long as the ink contains some metal and the parchment or paper is not very heavily limed, it is possible to visualise the ink and potentially recover text. Imaging ink on burned parchment has also been successful and work on recovering of images from degraded acetate stock film is in progress.

Preparation of the Roll for Scanning

When dealing with any archival item, especially those with damage, there is a prime requirement to do no further harm. Creating custom packaging for travel and scanning was undertaken by conservators at the archive in accordance with their established best practice.

To safeguard the roll during transportation from the archive to QMUL and during the scanning processes the parchment roll was packed in a specially designed enclosure (Plastazote® LD451: Preservation Equipment) [1]. Previous work established the suitability of Plastazote® for X-Ray scanning as it exhibits zero degradation in the X-Ray beam and is almost completely X-Ray transparent and hence does not interfere with the image collection.

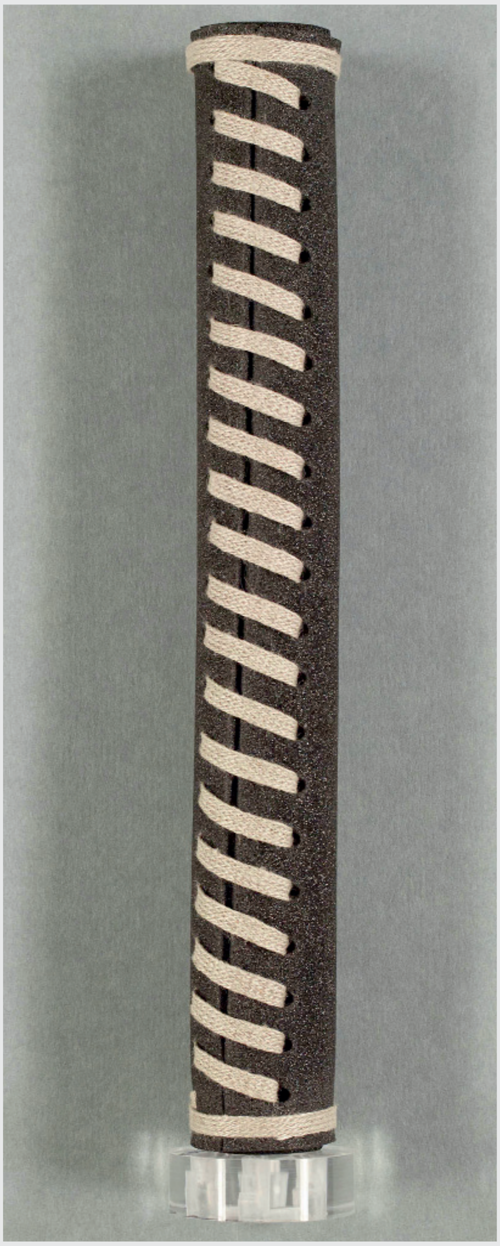
The final enclosure design, acceptable to current conservation guidelines, is shown in Fig 4, the roll was placed inside a laced tube made of Plastazote® LD451, attached to a button (Perspex®: RS Components) at the base. All components were held together with either unbleached linen thread or 5 mm linen tape.

3 Circular tear in parchment.

The packaging provides a secure enclosure keeping loose items together, but provides minimal humidity and temperature control. A major concern with exposing parchment objects to differing temperature and humidity conditions is dimensional changes in the parchment leading to ink delamination or other damage (Budrugeac et al. 2003; Bailey and Paul 1998). A briefcase lined with Plastazote®, was used to offer maximum protection and security during transportation to QMUL by one of the conservators from NRO. Arrangements were in place for the roll when not in the scanner to be stored on campus at QMUL Library Archive, which was able to offer suitably secure and environmentally controlled conditions.

Damage Mitigation

The temperature and relative humidity inside the scanner is constant at 22°C ± 1°C and 30% ± 5%. Archival storage standard of humidity and temperature is not possible in the scanner because of incompatibility with the camera system. The parchment roll and its travel packaging is allowed to come up



4 The laced Plastazote enclosure.

to ambient temperature and humidity inside the scanner before the scanning commences; this waiting time allows the parchment to relax under the new conditions, ensuring any movements are complete before the scanning process begins.

The scanning process is very sensitive to dimensional changes during a scan, we record data at a resolution of 20 microns, and therefore any dimensional change in the parchment at around half this resolution would cause intolerable blurring of the scan data. No blurring is observed therefore we are confident no temporary dimensional change occurs, beyond that caused by removal from archival storage standards.

X-rays are ionising radiation and as such have the possibility to cause damage to materials. There are two primary ways damage could occur: direct damage to the collagen matrix and excitation of reactive elements in the ink, leading to autocatalytic production of damaging free-radicals (Kolar and Strlic 2006). Regarding direct damage to collagen, a recent publication on the topic (Patten et al. 2013) finds no quantifiable extra damage to the collagen matrix after a prolonged X-ray exposure.

With careful consideration of the materials and elements likely present in the ink and parchment, we are able to tune our X-ray source to minimise any potential damage from them to either the ink or parchment.

Scanning Process

Unlike CT scanners for humans, which hold the patient still and move the X-ray source and detectors, the QMUL scanners require that the object being scanned be rotated on an axis between the X-ray source and camera. The Bressingham roll, still in its laced travel tube was placed inside a polyester tube to enable mounting in the scanner. The height of the Bressingham roll in the scanner meant that it was likely to wobble, introducing blurring and other errors into the scan. The end of the roll nearest the rotation stage is less prone to wobbling, so the roll was scanned in two passes with the roll inverted and repositioned to scan the top half. The X-ray energy was set to 30 keV to maximise the contrast between ink and parchment substrate. Multiple X-ray images (projections) were recorded with the roll being rotated by a fraction of a degree between each image. After a full rotation, the roll was lowered to scan the next section. This was repeated as necessary to scan the first half of the roll before turning it over to scan the inverted second half.

Total scan time took four days with breaks in the process for repositioning and calibration. The number of projections collected was more than 46,000 creating in excess of 120 gigabytes of data. The initial conversion of the large number of projections to a 3D image to verify accuracy of the data before it is passed to the Cardiff team for virtual unrolling took another working day.

Comparison between photographs of the accessible area of the Bressingham roll and the scan data confirmed successful ink imaging. Optimisation of the contrast and brightness parameters in the Drishti exploration software (Drishti <http://code.google.com>) enabled visualisation of text in the portion of the roll that was not accessible by conventional means. The internal structure of the roll was also virtually explored, locating the fused areas and some regions of unknown, unidentifiable, X-ray opaque contamination.

Preliminary results were communicated to NRO and the data handed to the computer vision experts in the Cardiff based team who would be responsible for creating a virtually unrolled image from the scan data.

5 False coloured tomographic 'slice' through the roll prior to unrolling. White is parchment; red is linen thread; yellow is Plastazote® LD 451 foam.

Image Segmentation

Before the roll could be virtually unrolled it needed to be identified and separated from the background air and container tubes. A tomographic slice through the roll is shown in Fig 5. The plastazote foam and the linen thread of the packaging are visible and must be segmented out.

6 Text on the unrolled portion of the parchment, seen with visible light (left) and X-ray Microtomography (right).

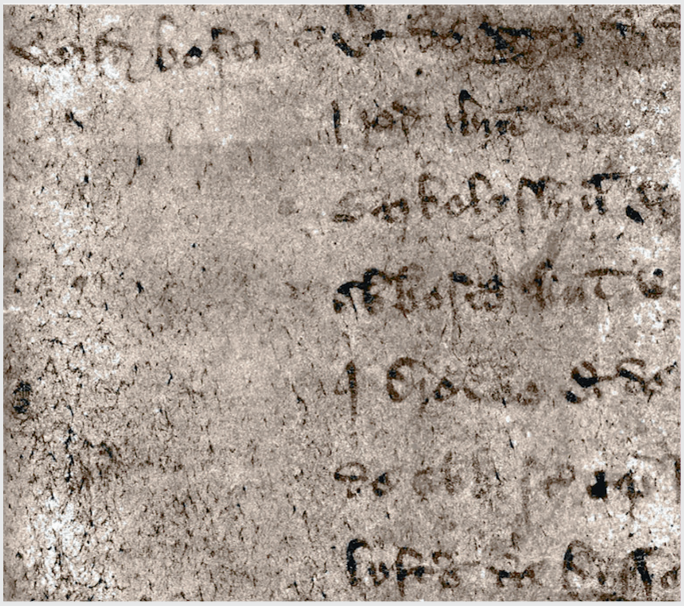
The 3-D data from the scanning process was sliced up into thousands of 2-D images, and the image segmentation (i.e. roll/air separation) performed on each of these. Since the parchment has degraded it exhibits fragmentation, variable sponge-like internal structure, and fused surfaces. The images were cleaned up by performing coherence-enhancing diffusion filtering (Weickert 1999). This makes the parchment structure more homogeneous, whilst simultaneously preserving the parchment's layer boundaries.

Next, an image segmentation method was applied that incorporates parchment layer thickness information together with the traditional pixel intensity information plus rules based on local geometry (Samko et al. 2014).

Virtual Unrolling

From each image, the centre-line of the roll was extracted, and then mapped to a straight line, which forms a column. The set of columns was used to generate the image of the virtually unrolled parchment surface by transferring the image pixels from the source images to the columns. However, due to inaccuracies in the previous image processing steps the result was highly distorted. Therefore this was corrected by realigning the columns using dynamic programming to locally stretch and contract sections.

Fig 6 shows a portion of the top, unrolled section of the roll imaged with both a camera and as scanned with X-rays and then virtually unrolled. There is more background texture in the X-ray image, but the text is still clear.



7 XMT revealed text from the portion of the roll just beyond the fusion boundary.

8 XMT revealed text from deep inside the roll.

It is interesting that some of the lighter ink in the camera picture appears much darker in X-rays, so although the ink may fade, the iron content of the ink is still large enough to give a strong X-ray contrast.

Results

The final result of scanning and virtual unrolling is an image of the full length of the left hand third of the roll. Examples of the revealed text are shown in Figs 7 and 8; these correspond to regions just at the point where the parchment fuses to itself, and towards the end of the parchment sheet (deep inside the roll). Some distinction between text and parchment texture is lost in images from deeper into the roll, but this may be overcome with more sophisticated image processing algorithms.

In the central portion of the roll, many of the layers of parchment are fused together, making the current unrolling technique (relying of identification of the parchment surface) unworkable. If this were the only problem, it might be possible to manually identify ink and tease out letters within this contiguous region. However, in this case the region is also associated with a contaminant that has similar X-ray attenuation properties to the iron gall ink, which at this time means we cannot distinguish between parchment and the ink. Nevertheless, the beauty of this method is that having scanned the roll, further experimentation and exploration can be performed on the 3D data set without the need to handle the original again. Although it may not be possible to recover all the text because of the contamination, ongoing refinements to the analysis will undoubtedly increase the proportion of recovered information.

The Bressingham roll was known to be part of a collection of documents detailing accounts and transactions of the Bressingham estate as such it would contain details of purchasers rights including fishing and woodcutting. The image of the unrolled portion of the Bressingham roll was inspected by the county archivist and local historians at the NRO. The revealed text was clear enough to learn how the Reeve of the manor bought the fishing rights from himself along with other interesting transactions.

Conclusion

This project has been an incredible collaborative opportunity, not only for archives but also for science. The techniques used have shown that the method of virtual unrolling and revealing text from inaccessible items is achievable, and provides a tool enabling content to be accessed from otherwise unfit collection items.

Endnote

[1] Plastazote® LD451 is a cross-linked closed cell polyethylene nitrogen expanded foam, which is an established material for use in package and storing of museum and archival material.

References

Bailey, A.J., and Paul, R.G. (1998): Collagen: a not so simple protein. In Journal of Society of Leather Technologists and Chemists, Vol 82, No 3, pp 104-110.

Budrugeac, P., Miu, L., Bocu, V., Wortman, F.J., and Popescu, C. (2003): Thermal degradation of collagen-based materials that are supports of cultural and historical objects. In: Journal of Thermal Analysis and Calorimetry, Vol 72, No 3, pp 1057-1064.

Davis, G.R., and Elliott J.C. (2003): High definition X-Ray microtomography using a conventional impact X-Ray source. In: Journal de Physique IV, France, Vol 104, pp 131-134.

Davis, G.R., and Elliott, J.C. (1997): X-Ray microtomography scanner using time-delay integration for elimination of ring artefacts in the reconstructed image. In Nuclear Instruments and Methods in Physics Research A, Vol 394, pp 157-162.

Davis, G.R., Evershed, A.N.Z., and Mills, D. (2012): Recent developments in the MuCAT microtomography facility. In: Developments in X-Ray Tomography VIII, Vol 8506, 850600E1-7.

Drishti: http://code.google.com/p/drishti-2 (viewed 20 may 2014).

Elliott, J.C., and Dover, S.D. (1982): X-Ray microtomography. In: Journal of Microscopy, Vol 126, No 2, pp 211-213.

Gonzalez, L.G., and Wess, T.J. (2013): The effects of hydration on the collagen and gelatin phases within parchment artifacts. In: Heritage Science, Vol 1:14.

Gonzalez, L.G., Hiller, J., Terrill, N.J., Parkinson J., Thomas, K., and Wess, T.J. (2012): Effects of isopropanol on collagen fibrils in new parchment. In: Chemistry Central Journal, Vol 6:24.

Kolar, J, Strlic, M., Balazic, A., Smodis, M., Malesic, J., and Sala, M. (2006): Prototype InkCor Treatments: evaluation of effectiveness. In: Strlic, M., and Kolar, J. (eds): Iron gall inks: on manufacture, characterization, degradation and stabilization, National and University Library, Ljubljana, pp 247-253.

Larsen, R., Poulsen D.V., and Axelsson, K.M. (2011): Scientific Approach in Conservation and Restoration of Leather and Parchment Objects in Archives and Libraries. In: Engel, P., Schiro, J., Larsen, R., Moussakova, E. and Kecskemeti, I. (eds): New Approaches to Book and Paper Conservation-Restoration, Horn and Wien: Verlag Berger, pp 239-258.

Mills, D., Samko, O., Rosin, P., Thomas, K., Wess, T., and Davis, G.R. (2012): Apocalypto: revealing the unreadable. In: Developments in X-Ray Tomography VIII, Vol 8506, 850600A1-5.

Patten, K., Gonzalez, L., Kennedy, C., Mills, D., Davis, G.R., and Wess, T. (2013): Is there evidence for change to collagen within parchment samples after exposure to an X-ray dose during high contrast X-ray microtomography? a multi technique investigation. In: Heritage Science, Vol 1:2.

Samko, O., Lai, Y., Marshall, D., and Rosin, P.L. (2014): Virtual Unrolling and Information Recovery From Scanned Scrolled Historical Documents. In: Pattern Recognition, Vol 47, No 1, pp 248-259.

Weickert, J. (1999): Coherence-enhancing diffusion filtering. In: International Journal of Computer Vision, Vol 31, No 2/3, pp 111-127.

Suppliers

Preservation Equipment Ltd, Diss, Norfolk IP22 4HQ, United Kingdom, Tel +44-1379-647400, www.preservationequipment.com (Black Plastazote - 170-4512).

RS Components Ltd, Corby, Northants NN17 9R6, United Kingdom, Tel +44-8457-201201, http://rs-online.com (Perspex Rox 50mm diameter - 824-626).

German Title and Abstract

Apocalypto: Die Schriftrolle von Bressingham wird erschlossen

“Können moderne Abbildungs- und Bildverarbeitungsverfahren den textlichen Inhalt von stark geschädigten Pergamentschriftrollen freilegen?” Das zahnmedizinische Institut an der Queen Mary Universität in London ist das führende Zentrum für hochkontrastige Röntgen-Mikrotomographie. Das Apocalypto Projekt (griech.: Enthüllung) umfasst unsere Zusammenarbeit mit Experten für bildgebende Verfahren des Instituts für Informatik an der Universität Cardiff. Aus dieser Zusammenarbeit wurden Techniken und Arbeitsschritte entwickelt, die es ermöglichen, den textlichen Inhalt von beschädigten Pergamentschriftrollen teilweise lesbar zu machen. In ersten Ergebnissen konnten wir das linke Drittel einer verbackenen Pergamentrolle virtuell vollständig entrollen und mehr als 50 Zeilen Text lesbar machen – das Fünffache dessen, was bisher mit herkömmlichen Methoden zugänglich war. Wir sind zuversichtlich, die Schriftrolle vollständig virtuell entrollen zu können, da sich die Datenverarbeitungstechnik stetig verbessert. Wir glauben, dass dieser Artikel schlüssig darlegt, dass unsere Techniken bei Objekten aus dem Kulturerbe anwendbar sind und wertvolle Informationen für Restauratoren und Archivare freilegen können.

Authors

David Mills completed a PhD in Laser-Materials interactions in 2006 and since then has been working on new ways to understand and apply new non-invasive imaging and analysis techniques to the analysis of a wide variety of materials including paper and parchment.

Dr. David Mills, Queen Mary, University of London, Institute of Dentistry, Francis Bancroft Building, London E1 4NS, United Kingdom, Tel +44-0207-882-5978, d.mills@qmul.ac.uk

Antoinette Curtis qualified as an archive conservator on the Society of Archivists’ Conservation Training Scheme in 1976, and has spent a long and varied career in conservation with the Norfolk Record Office’s designated collection since then. Her knowledge and experience has been challenged when working on items, which were water damaged in the fire at the Central Library, Norwich in 1994. The work was particularly demanding in the field of parchment conservation, and it is through this work that I have developed an interest in new methods of treating parchment.

Antoinette Curtis, Norfolk Record Office, The Archive Centre, Martineau Lane, Norwich NR1 2DQ, United Kingdom, Tel +44-01603-222670, antoinette.curtis@norfolk.gov.uk

Graham Davis obtained a PhD in medical electronics in 1984 andshortly thereafter began work on the development of X-ray microtomography (XMT). Designing scanners and software algorithms with accuracies exceeding commercially available systems, he is well recognised in this area of development and has served on the European Standards Committee CEN/TC 138/WG 1/AH 1 Computed Tomography. He is now a Reader in 3D X-ray Imaging, with many international collaborators using his 3D imaging resources.

Dr. Graham R. Davis, Queen Mary, University of London, Institute of Dentistry, Francis Bancroft Building, London E1 4NS, United Kingdom, Tel +44-0207-882-5967, g.r.davis@qmul.ac.uk

Paul L. Rosin is Professor at the School of Computer Science & Informatics, Cardiff University, having previously worked in Italy and Australia. His research interests include low-level image processing, machine vision approaches to remote sensing, medical and biological image analysis and the analysis of shape in art and architecture.

Prof. Paul Rosin, School of Computer Science & Informatics, Cardiff University, Cardiff CF24 3AA, United Kingdom, Tel +44-29-2087-5585, paul.rosin@cs.cf.ac.uk

Yu-Kun Lai received his PhD degrees in computer science from Tsinghua University, China in 2008. He is currently a lecturer of visual computing in the School of Computer Science & Informatics, Cardiff University. His research interests include computer graphics, geometry processing, image processing, and computer vision. He is on the editorial board of The Visual Computer.

Dr. Yu-Kun Lai, School of Computer Science & Informatics, Cardiff University, Cardiff CF24 3AA, United Kingdom, Tel +44-29-2087-6353, yukun.lai@cs.cf.ac.uk