Apocalypto - Revealing lost text with XMT

David Mills†, Graham R. Davis†, Yu-kan Lai‡, Paul Rosin‡

†Queen Mary University of London. Mile End Road, London. UK

‡School of Computer Science & Informatics, Cardiff University, Cardiff. UK

Keywords: Microtomography, Parchment, Heritage

ABSTRACT

"*Can brute-force high-contrast tomography techniques and image processing techniques retrieve textual content from damaged heritage materials?*"

The Dental Institute at Queen Mary University of London (QMUL) is the leading centre for very high contrast X-Ray Microtomography imaging. The Apocalypto Project is our collaboration with the heritage community and 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 textual content from moisture-damaged parchment rolls. This article will also present some initial results from burned and heat shrunken parchment rolls, an insect damaged Mamluk cap and a birch bark roll.

1. INTRODUCTION

The work-flow and parameters for scanning histological specimens of hard tissues, teeth and bones primarily, are well known. The protocols and techniques for XMT of heritage objects (often consisting of preserved animal derived soft-tissues) are less well explored, and more difficult to generalise anyway due to the large variation in composition, construction and condition.

The choice to use XMT over a medical CT scanner when investigating heritage material will depend on the information required and the size of the object. Medical CT scanners have been used to great effect with mummified human[1] and animal remains,[2] and to image objects made from organics, ceramics and glass in soil blocks taken from early medieval cemetery of Lauchheim in Baden-Württemberg.[3] While the results from these scans are acceptable in terms of providing gross morphological information about the objects, there is often no attempt to use quantitate information from the scans to probe the make-up of the objects.

Where XMT scanners are applied to heritage research, they are primarily used for higher resolution imaging of smaller objects for example the Antikythera Mechanism,[4] building materials and paint samples from Van Gogh paintings.[5] Attempts to use standard contrast XMT to detect and visualize writing in books and rolled documents has only been successful where the inks have been largely metallic (almost pure cinnabar - mercury sulphide). This article will demonstrate the use of high-contrast XMT using the MuCAT-2[6] scanner at QMUL to recover text written with inks of much lower intrinsic x-ray contrast.

2. THE HERITAGE OBJECTS

2.1 The Bressingham Roll

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

2.2 The burned Diss Heywood Title Court roll

A severely burned and heat-shrunken parchment Title Court roll from the Diss Heywood, dated 16th century (NRO, MC 1841/1-2, 856X2). The roll is part of a larger collection of annual records containing information regarding tenant farming on land belonging to the Manor of Diss Heywood.

The roll has been charred and shrunk by fire, the fused roll is roughly oval in cross-section, approximately 50mm in the long axis and stands approximately 270mm high. The fire has rendered the writing illegible due to shrinkage, distortion and discolouration of the now heat-embrittled parchment. The brittleness of the parchment precludes any attempt to unroll it physically.

2.3 An Egyptian child's cap.

A round child's cap dating from the Egyptian Mamluk period, 1250 - 1517 (Ulita Ref. No. 2008.11). The cap is composed of four separate layers. The top outer fabric is plain-woven with a repeating striped design. Beneath this fabric is a fibrous paper interlining, with black inscriptions followed by a wadded layer, composed of individual bundles of rolled fibres. The cap is lined in a natural coloured plain-woven fabric.

It is rare to find any inscriptions included in garments dating from this period, nothing is known about their likely content. The inscriptions on the visible portions of the interlining have been shown to have been made with an iron-containing ink.

2.4 Early 21st Century birch bark roll

A small birch bark roll in private ownership dating from 2009. The roll consists of a single sheet of European silver birch bark approximately 200 mm long, by 90 mm high. A message has been embossed onto the bark with a blunt stylus, the content of the message is unknown due to the roll having been sealed.

Birch bark manuscripts are documents written on pieces of the inner layer of birch bark, which in some areas has been used for writing before the introduction of paper. Evidence of birch bark for writing goes back many centuries and in various cultures. Ink is not always required as the the birch itself will darken under pressure from a stylus as the inscription is made. Therefore, any X-ray contrast will only come from local changes in the density of the birch bark sheet caused by the stylus pressure.

3. THE SCAN PROTOCOLS

3.1 Rolled documents

Both the parchment rolls were scanned while packed in custom fitted Plastazote LD45* enclosures. These provide support and stability for the roll during the scanning process. The production of parchment from animal skins uses lime in the hair removal and bleaching steps, this causes a calcium background attenuation that can swamp the additional attenuation from iron and copper in the ink. The X-ray energy is set to 30 keV to achieve ~10% transmission though the object.

The detector size effectively limits the maximum width of the scanned object to ~2500 x 800 pixels per projection, this in turn sets the upper limit on the resolution of the scan. To detect the thickness of pen ink on parchment we estimate a scan resolution of at least 30 µm / voxel is required. The highest scan resolution taking into object size, scan time† and estimated required resolution was 20 µm / voxel, so all scans were performed at this voxel size.

*Plastazote is a low density nitrogen foamed plastic, which is almost X-ray transparent and does not degrade in the X-ray beam during a typical scan duration.

†Maximum 24 - 48h scans are favoured to limit total X-ray dose to the object, and minimize systemic drift during the scan.

The rolls were scanned standing on end as a series of non-overlapping 'blocks', each block consisting of 2901 projections. The full scan of the whole of the Bressingham roll contains 17 blocks, and a total of 34119 projections. Total scan time was on the order of 5 days. The burned Title Court roll is in the process of being scanned, it is estimated to require more than 14 days of scanning due to its size. Beam-hardening calibration scans and adjustment of X-ray generator parameters is performed after every three blocks.

The birch bark roll was scanned with the lower 20mm of the roll inside a thin polycarbonate tube, providing support and a mounting point in the XMT scanner. The X-ray energy was set to 25 keV to maximize contrast in the weakly attenuating bark. Four non-overlapping blocks were scanned with 1891 projections in each block.

Beam-hardening correction for all rolls, parchment and birch was performed using in-house developed code,[7] against a PMMA[‡] virtual step wedge. Reconstruction of the projection data into a 3D volume was performed with in-house filtered back projection algorithms implemented in CUDA, running on NVIDIA graphics cards.

3.2 Mamluk cap

The cap was mounted on a polyester fibre filled form, this was required to be kept in place during the scan. The dimensions of the cap on its mounting form were such that collection of a full XMT scan dataset was impossible in the time allowed. Instead, the XMT was used as a high contrast radiography system. The cap was mounted at a 45 degree angle between the X-ray aperture and the detector, such that X-rays passed though the base of the mounting form and though the region of interest to the detector, this minimised the total amount of polyester fibers co-imaged with the paper interlining. Two scans were made at 20 keV and 30 keV in attempt to try differential absorption imaging. The imagining resolution in the plane of the ink was 30 µm. A total of 20 images at each energy were collected and summed together in IDL. A difference image (30 keV - 20 keV) was also produced. No reconstruction was made.

4. RESULTS

4.1 The Bressingham Roll

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[10] 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.

4.1.1 Image Segmentation and virtual unrolling

Before the roll could be virtually unrolled it needed to be identified and separated from the background air and container tubes. A tomographic slice though the roll is shown in Figure 1. The plastazote foam and the linen thread of the packaging are visible and needed to be segmented out. 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.[8] 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.[9]

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. Figure 2 shows a portion of the top, unrolled

[‡]Poly(methyl methacrylate) is a close approximation for most organic materials

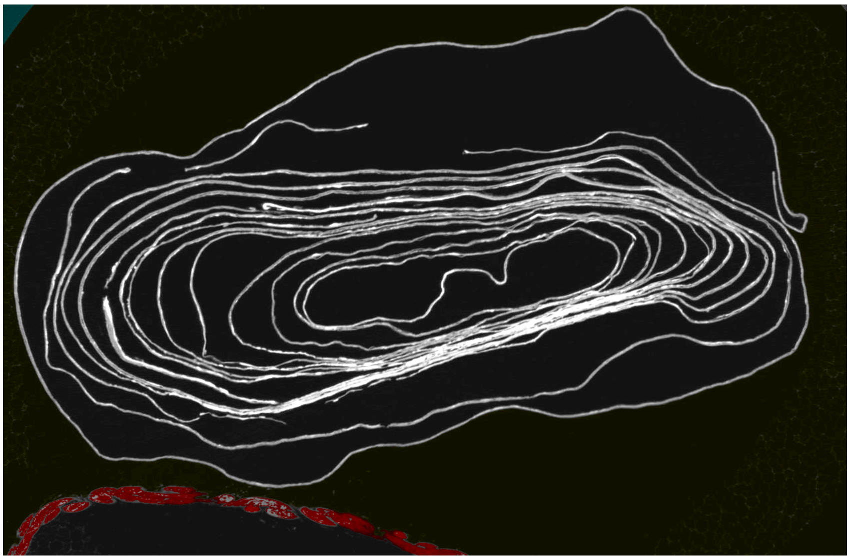

Figure 1. Tomographic slice though the Bressingham Roll

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. 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 sufficient to give a strong X-ray contrast.

Figure 2. Comparison of text reveled by XMT and optical photography

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 Figures 3 and 4; 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.

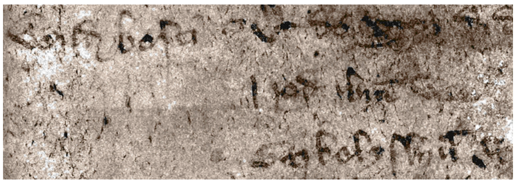

Figure 3. Revealed text from just inside the fused region of the Bressingham roll

Figure 4. Revealed text from deep inside the Bressingham roll

4.2 Burned Title Court roll

The charring of the roll obscures any text on the visible portion of the parchment surface, so there is nothing to compare scan data against. The shrinkage of the parchment in the fire has also consolidated the ink, increasing the density of the iron in it, hence increasing its X-ray attenuation. Preliminary scan data, two blocks worth, were collected. Bright areas in the tomographic slices, indicative of ink, were imaged with drishti, two portions of text revealed this way are displayed alongside a tomographic slice in Figure 5. The scan reveals the roll is comprised form several parchment sheets co-wound and now adhering together. New algorithms will have to be developed to enable virtual unrolling of this scroll.

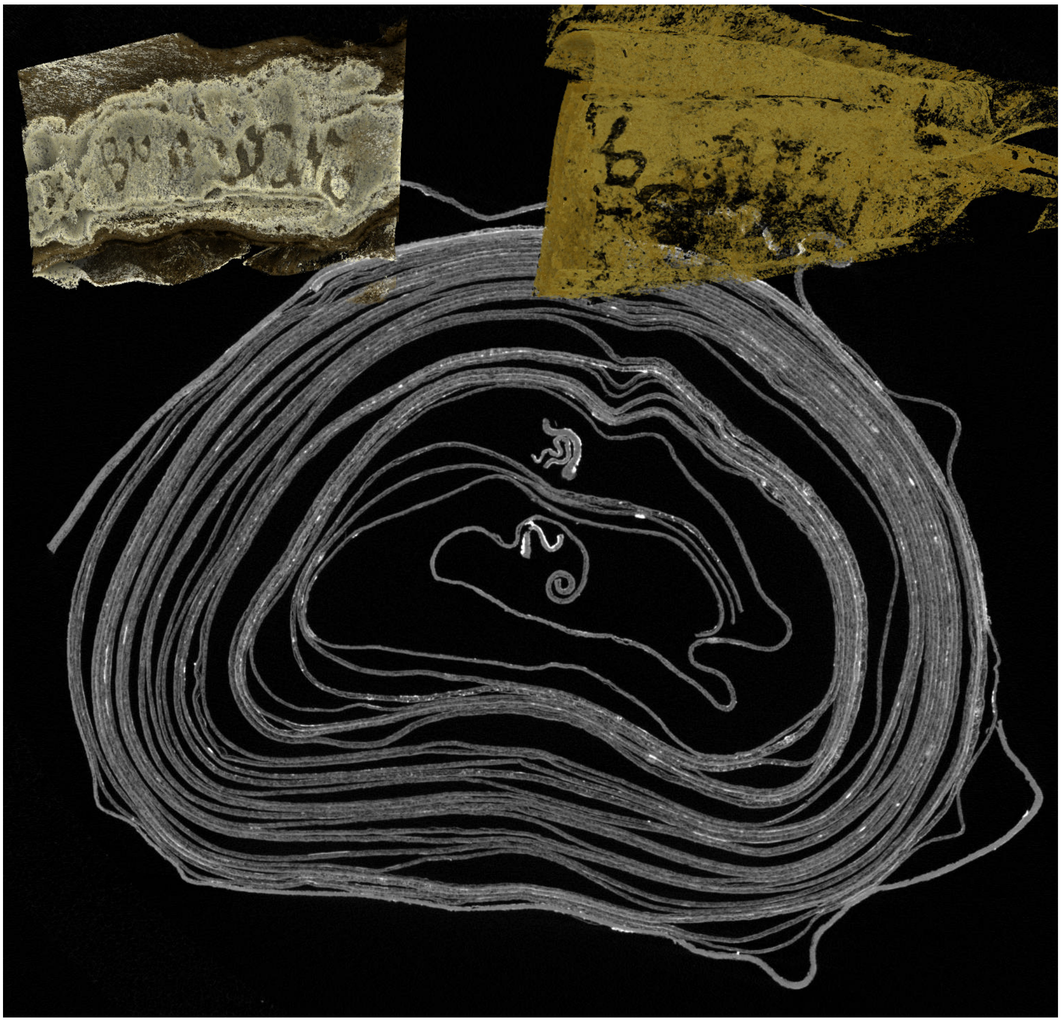

Figure 5. Burned Title Court roll tomographic slice, with initial revealed text inset

4.3 Birch bark roll

The roll is sealed and rolled with the writing on the inner surface, thus no comparison has been made between the scan data and the real inscription. The X-ray contrast mechanism appears to be a local change in the texture of the bark in the region of the writing. The bark structure is collapsed by the stylus pressure, locally increasing the density and changing the texture. The text is only visible when the scan data is volume rendered, this may prove an interesting challenge for the unrolling process.

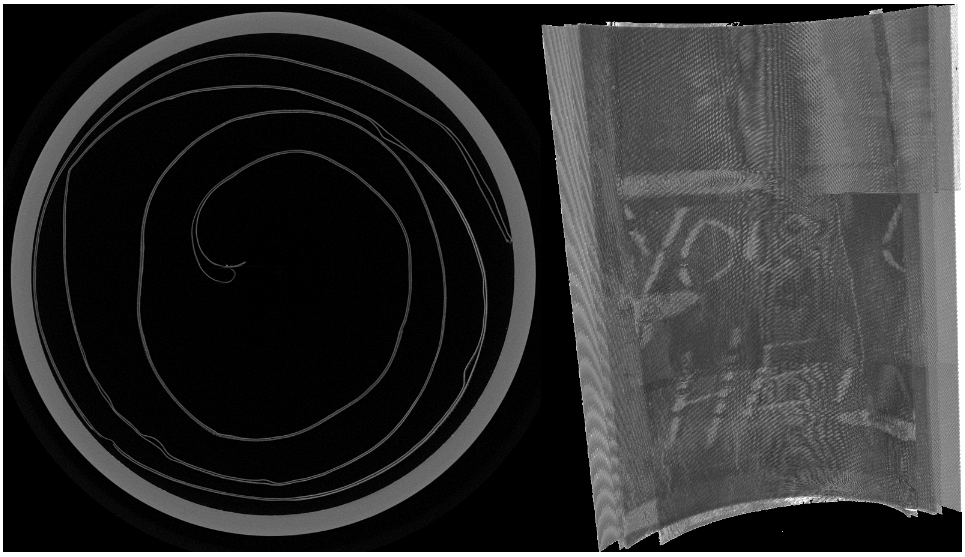

Figure 6. Text revealed as a difference in the texture of birch bark

4.4 Mamluk cap

The text on the paper interlining makes up a very small fraction of the imaged volume of the cap; the total X-ray path though the cap and its mount was on the order of 10 cm. We were able to image the region where the ink was known to be, however the large background from the polyester wadding of the mount rendered it impossible to unequivocally claim imaging of the text. Removal of the cap from the mount before imaging would be required to progress further.

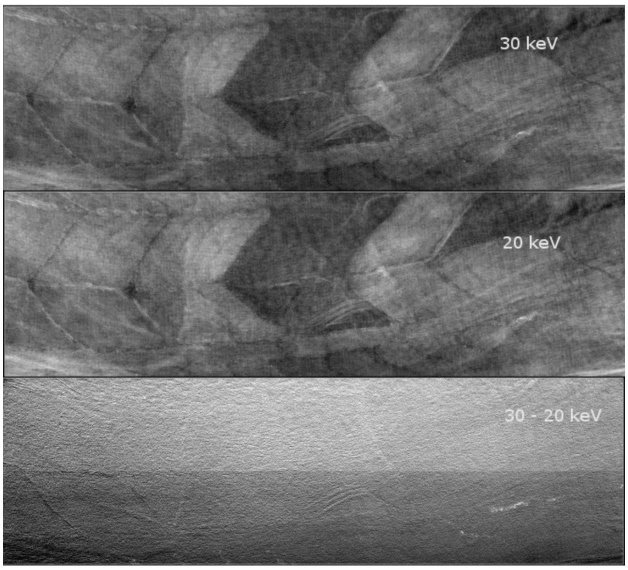

Figure 7. High-contrast differential radiography of the Mamluk cap.

5. CONCLUSIONS AND FURTHER WORK

We have shown that the revelation of some textual content from damaged heritage items is feasible under favourable conditions; good ink contrast and small enough object size, using the brute force contrast XMT approach. The challenge is to translate our successes in this field into a more generally applicable form and to continue to investigate the widely different materials humankind has used for documentation, as there will be cases where only very high contrast tomography will have any chance of revealing unknown text.

ACKNOWLEDGMENTS

Development of the MuCAT scanner was funded by the Engineering and Physical Sciences Research Council, EP/G007845/1. The two parchment rolls were loaned by the Norfolk Record Office. Access to the Mamlik cap was provided by Jacqueline Hyman and ULITA - University of Leeds International Textiles Archive. The birch bark roll was prepared and loaned by Meagen Smith.

REFERENCES

1. Thompson, R. C., Allam, A. H., Lombardi, G. P., Wann, L. S., Sutherland, M. L., Sutherland, J. D., Soliman, M. A.-T., Frohlich, B., Mininberg, D. T., et al., "Atherosclerosis across 4000 years of human history: the Horus study of four ancient populations," Lancet 381(9873), 1211–1222 (2013).
2. Malgora, S., Borgonovo, S., Moioli, M., Di Giancamillo, A., Domeneghini, C., Di Giancamillo, M., "Investigation of the Trento cat mummy," Journal of Biological Research - Bollettino della Società Italiana di Biologia Sperimentale 85(1) (2012).
3. Stelzner, J, Ebinger-Rist, N, Peek, C and Schillinger, B 2010 The Application of 3D Computed Tomography with X-Rays and Neutrons to Visualize Archaeological Objects in Blocks of Soil. Studies in Conservation 55, 95–106.
4. Freeth, T., Bitsakis, Y., Moussas, X., Seiradakis, J. H., "Decoding the ancient Greek astronomical calculator known as the Antikythera Mechanism," Nature (2006).
5. Dik, J., Janssens, K., Van Der Snickt, G., van der Loeff, L., Rickers, K., Cotte, M., "Visualization of a Lost Painting by Vincent van Gogh Using Synchrotron Radiation Based X-ray Fluorescence Elemental Mapping," Anal. Chem. 80(16), 6436–6442 (2008).
6. Davis, G., Evershed, A., Elliott, J., Mills, D., "Quantitative x-ray microtomography with a conventional source," SPIE Optical Engineering + Applications 7804, S. R. Stock, Ed., 78040I–78040I–8, International Society for Optics and Photonics (2010).
7. Evershed, A. N. Z., Mills, D., Davis, G., " Multi-species beam hardening calibration device for x-ray microtomography," SPIE Optical Engineering + Applications 8506, S. R. Stock, Ed., 85061N–85061N–12, International Society for Optics and Photonics (2012).
8. Weickert, J., "Coherence-enhancing diffusion filtering," International Journal of Computer Vision 31(2-3), 111–127 (1999).
9. Samko, O., Lai, Y.-K., Marshall, D., Rosin, P. L., "Virtual unrolling and information recovery from scanned scrolled historical documents," Pattern Recognition 47(1), 248–259 (2014).
10. Limaye, A., "Drishti: a volume exploration and presentation tool," presented at SPIE Optical Engineering + Applications, 17 October 2012, 85060X–85060X–9, SPIE.