

3D COLOUR IMAGING FOR CULTURAL HERITAGE ARTEFACTS

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ABSTRACT:

This paper will discuss work in progress for the metric 3D recording and colour imaging of museum objects and the opportunities it opens up to broaden scientific knowledge about these artefacts. The following recording technologies will be discussed and compared with regard to imaging complex objects: phase-shift laser scanning, handheld laser scanning, high-resolution 3D colour laser scanning, PTM and photogrammetry. The evaluation criteria will include resolution, accuracy, noise, colour fidelity, mobility of the sensor, and data processing chain. The paper will explore the possibilities of integration of 3D image analysis with the daily work in a museum, tailored to conservation and curation. To plan and predict results, a decision tree will be delineated suggesting one or more techniques to answer specific curatorial or conservation questions. Integration with other imaging techniques for cultural artefacts, including IR and UV photography, microscopic imaging and SEM surface recording will also be considered. Available imaging technology will be discussed keeping in mind the UK museum framework; the research focus lies on the evaluation of diverse recording technologies while producing quantitative and qualitative evidence of geometry, surface and damage. The approach will therefore develop a bridge between conservation analysis methods and engineering metrology, by closely analyzing the possibilities and limitations of imaging technologies, with the goal to lead to a comprehensive knowledge about cultural heritage artefacts.

1. INTRODUCTION

3D images are recognized by museum specialists for opening up new technological possibilities for research, exhibition display and education. Traditional documentation techniques (sketches, to-scale hand and isometric drawings, text, photographs) have been translated into modern digital techniques. ICT (information communication technologies) and E-Science in Arts and Humanities research towards the pursuit of a common infrastructure; 'digital humanities' help to mediate the outcome to the interested public.

Nevertheless, 3D digital surrogates, or 3D high-resolution colour representations of digitized museum objects, have not yet been assigned a standardized procedure in museums and collections; they have not yet been integrated in the conservation laboratory workflow or most computer-based collection management systems.

Administrative factors such as high cost and data management in museums are a key obstacle for the development of a best practice for handling 3D digital images of museum objects (Cooper et al. 2006). Limited financial resources restrict the possibilities of most museums to take part in technological research. At the same time museums seek to provide better service for conservation, scholarly study and public display (Evans 2006, p.552).

In the eye of some cultural heritage professionals the legacy and importance of the 2D record is stronger than the new technologies; 3D imaging still ranges under the label of 'expensive and time intensive methods' with uncertain outcome and low efficacy versus conventional documentation and assessment methods.

The need for infrastructure developments, a new understanding and new standardized ways of communication, and the design of feasible practical approaches for cultural heritage (CH) professionals was highly stressed by the EPOCH project

(Arnold & Geser 2008). New ways of exploiting 3D imaging and replica in a museum context were discussed by (LaPensée et al. 2006). A user-friendly, rapid workflow for automatic 3D colour scan acquisition and robust 3D reconstruction was designed together with the conservators to solve the assembly task of thousands of fresco fragments by (B. J. Brown et al. 2008). Another excellent example of synergetic effects of multidisciplinary documentation of a museum object, including high-resolution 3D, is the 'Mona Lisa' project at the Louvre (Mohen et al. 2006).

From an engineering point of view guidelines for optical non-contact measurement are maturing (VDI/VCI 2643, BSI PD 6461-1995, ISO/DIS 10360-8). Engineering metrology can provide a framework in which different sensors can be examined and compared, but the work towards an accepted terminology and methodology is still ongoing (Beraldin et al. 2007).

For a 3D record of a museum object to be convincing for the cultural heritage end user as a 'valuable 3D asset' it must show quantifiable evidence of geometric and colorimetric fidelity; such a high-quality dataset contributes to a comprehensive documentation and essentially to object understanding and accessibility.

Research at UCL seeks to enable and empower CH specialists to actively participate, give precise specifications of the digitizing process for the creation of digital surrogates and digital assets which are fit for purpose and augment understanding about the value of their artefacts.

The outcome of this research aims to leverage a broad knowledge base and promote the technology transfer necessary to enable CH specialists to have their voice in the decision making process.

To this end, this paper describes the current recording technologies at UCL, and how user testing, and recording sensor comparisons are leading to an end user oriented decision tree.

2. 3D IMAGING TECHNOLOGY AT UCL

UCL currently owns a range of active and passive measurement technologies, including a scanner developed specifically for imaging cultural heritage artefacts.

2.1 3D laser scanning instrumentation/ active methods

Scanner model	points/sec	resolution [mm]	accuracy [mm]	range [max in m]	object size	mobility	record type
Arius3D Foundation Model 150 Colour Scanner (CMM)	3000	0.1	0.025	0.08	0.01 to 0.8m, small to medium size museum objects	none	3D colour laser scanning, triangulation scanner
Arius Rover 100 portable laser scanner (Tripod)	3000	0.1	0.025	0.08	0.01 to 0.4m, small museum objects	mobile	3D colour laser scanning, triangulation scanner
Metris K-Scan UCL type	19200	0.4	0.25	7.5	0.15 to 12m, medium size object, furniture	transportable	3D laser scanning, Triangulation scanner
Faro Photon 120 with colour option (Nikon D300)	976,000	2	+/-2	120	0.3 to 100m, bigger museum objects, interiors, exteriors, architecture	Highly mobile, on site recording	3D laser scanning with calibrated digital camera as colour option, phase shift laser scanner

Table 1 Available 3D laser scanning technologies at UCL.

The **Arius3D Foundation Model 150** and the **Arius 3D Rover 100** are both **3D colour laser scanners** for small to medium sized museum objects. The Foundation Model is a scan head fixed to a CMM in a temperature and humidity-conditioned room, whereas the Rover is portable. Both are used to create detailed object ‘fingerprints’ of a range of artefact types and deliver 3D coloured point data at a sampling interval of 0.1mm (~250 dots per inch) at an accuracy of the order of 0.025mm over the surface of an object. The scanner collects 3D geometry information through the use of a laser triangulation system, whilst colour is simultaneously collected by analysis of the reflected light from three RGB lasers. These capabilities confer the researcher the ability to produce 3D models which have a level of geometric and colour standardization that easily surpass any other available museum recording process.

Both scanners are used at UCL to produce detailed 3D coloured images for research and multimedia outputs.



Figure 1 Digital image of a Sepik Yam Mask from UCL Ethnographic Collections and object handling in the scanner room by the curator. The mask was scanned as part of the UCL *E-Curator* project.

For museum objects up to a size of 10 metres a **Metris K-Scan system** has been deployed. It consists of a handheld scan head and a mobile CMM (K610 camera bar) with three synchronised linear camera units. A number of infrared LEDs built into the handheld scan head housing are imaged and accurately tracked by the Metris Optical CMM via triangulation. Tracking of the scanner head delivers scan head position and orientation (6DOF) in real time enabling the operator to freely walk around and efficiently acquire surface scans of the measurement object in a tracked field of about 6 x 6 x 3 metres.

The scan head is a laser triangulation system that emits a laser line. The system measures the two-dimensional projection of the laser line on an object, using a CCD camera to calculate a 2D profile. The width and depth of field is 50mm, the accuracy (best fit sphere) is 15 µm RMS, at a stand-off (distance to the object) of about 100mm. The 6DOF tracking of the KCMM combined with the 2D profile deliver a scan line ordered 3D point cloud. The quality of the data depends on the object’s surface and can be adapted by varying laser brightness and software filtering parameters according to the object properties. After alignment of the single scans and post-processing, the resulting polygon mesh can be textured with photographs taken on-site.



Figure 2 The Metris K-Scan was used in a Norwegian-British collaboration to record the 12m long *Solomon Island war canoe* at the British Museum. Metric survey and virtual reconstruction was paired up with anthropological considerations about the digital repatriation of the 3D virtual object back to the Solomon Island source community.

A **FARO Photon 120** laser scanner is used to document larger objects, building interiors and exteriors. Through a vertically spinning mirror and simultaneously horizontally rotating scan head 3D measurements around the sensor position are collected (angle 155° – vertical, 360° -horizontal). 3D position of a point in space is calculated by comparing the phase shift in the reflected laser light to a standard phase. The point cloud can be overlaid with colour information captured with a calibrated Nikon D300s camera.



Figure 3 The *Virtual Flaxman Gallery* project of UCL Museums and Collections will discover changes in the decorative scheme since its inauguration in 1849, and will integrate high-resolution scans of single relief casts.



Figure 4 The UCL Grant Museum of Zoology was fully documented by 3D colour laser scan before its move to a new location. Panoramic photographs applied on the high-resolution scans allow the identification of the single specimens.

2.2 Image based methods/ passive recording methods

Digital close range photogrammetry is a robust and established non-contact optical method for the documentation of museum artefacts. The equipment consisting of a digital SLR

camera (Nikon D700) and lighting equipment is easily transportable to museum and fragile objects. It is capable of delivering high-resolution colour images ideal for the documentation of current condition and damages on the surface of the artefact enabling the visualisation of details of the order of 50 μm .

A workflow has been developed that allows 3D colour documentation of small to medium sized objects by multi-photo bundle adjustment with the help of pre-produced calibrated boards with coded targets. A calibrated Nikon D300 or D700 is used to produce images from a systematic range of viewpoints. The images are processed in VMS (Vision Measurement System (Shortis & Stuart Robson 2001) and Socetset (BAE Systems). The final model can be output as pointcloud or TIN (Triangulated irregular network in a number of formats: vrml and ply being preferred).



Figure 5 Image acquisition pipeline of a Petrie Museum object, a fragile cartonnage mask (UC45849). The images show: coded targets, calibration object, photogrammetry in progress, network geometry in VMS, output results as texture mapped TIN.

Due to the high resolution and colour fidelity these 3D images are very convincing to conservators and curators even though the underlying geometry might not be as detailed as a 3D scan sampled from an active technique. This type of image enables the detailed inspection of damage and condition, being able to mimic the use of a low magnification hand lens.

A **Polynomial Texture Map (PTM)** is generated from the mathematical synthesis of multiple digital photographs of an object taken from a stationary camera position (Malzbender et al. 2001). PTM is used at UCL for small to medium-sized near-flat objects.

A calibrated camera is fixed on top of the acrylic dome structure (1030mm diameter) with a series of 64 separately controlled electronic flashes; the object is placed underneath the dome and the suitable lens chosen to fill the frame. A series of images is taken with known lighting directions. All photographs contain different highlights and shadows. A viewpoint-specific, per-pixel reflectance function computes a model that enables interactive lighting by the viewer.

The outcome of PTM recording is a 2D high-resolution interactive image especially useful for the viewing of shape, reliefs or writings on objects. Additional filters such as specular enhancement, diffuse gain and light direction extrapolation can be helpful for the interpretation. Ongoing research by Lindsay MacDonald "Quantifiable colour from laser scanning and PTM imaging" will further explore the technical limitations.



Figure 6 Toy car image with illumination of one tier of flashes. Ford Sunliner UCL Pathology Collection, Reg.No.315678

2.3 Integration of other imaging technologies

Optical imaging methods are executed in the visible light spectrum between about 380 nm to 760 nm, but the inclusion of images can bring to light new insights about museum artefacts.

In conservation other image based investigation and analysis techniques are used to answer questions about the object. The following methods are described in detail in (Mohen et al. 2006, p.78ff): raking light photography (visible light spectrum), UV (ultraviolet) photography (20 to 400nm), IR (infrared) photography record (750 to 10⁵nm), radiography, X-ray fluorescence spectrometry, RAMAN spectrometry, multi-spectral imaging. Further technologies are used to deliver detailed sub-millimetre images including confocal microscopy and SEM (scanning electron microscope). Material analyses are often executed with sensors that deliver spectra of samples, e. g. FT-IR (Fourier transformed spectroscopy).

3. 3D IMAGING REQUIREMENTS FOR A MUSEUM END USER

3.1 UK Museum framework and conservation ethics

One of the main concerns of conservators is the obligation to conduct a careful and thorough documentation and recording of an object as part of a collection, before and after a preservation and conservation treatment (ICOM 2006, sec.2,20). The Codes of Ethics call for *written and pictorial records* (ECCO 2004) and for the application *highest possible standards* of as part of the diagnostic examination and recording of an object. This does not only entail a photographic overview of objects, but extends to other forms of imaging, for example textual description or microscopic documentation.

The UK Museum Documentation Standard is SPECTRUM (1996) and forms the basis of work undertaken within UCL Museums and Collections.

CH professionals require the documentation of provenance of the object itself, conservation treatment, condition and the 'digital provenance', for example detailed information about the imaging technology used. Curators and conservators are generally most interested in the source or 'primary data', e.g. direct measurement with a high level of fidelity, rather than 'secondary data' (approximation by triangulation, reconstruction, multimedia output).

All steps and decisions from recording, post-processing to the 'digital born data' and final model should be tracked according to the London Charter with 'scholarly rigour' (Beacham et al. 2006).

3.2 User interface testing and evaluation criteria

Within the *E-Curator project for 3D colour scans for remote object identification and assessment* (2007-08) first user testing on a newly developed prototype was executed.

The prototype consists of a web-based interface where a 3D image is presented paired up with metadata relevant to collections management and 3D recording (S. Robson et al. 2008). The prototype was used to explore central data storage, and online viewing of the 3D models without the need for specialist software.

User testing was executed throughout varied disciplines. 20 cultural heritage specialists, 13 of whom were either curators or conservators, were interviewed in a semi-structured process whilst browsing their 3D objects on the E-Curator prototype interface. In a brainstorming session further requirements for

improved handling and viewing towards the aim of assessment of museum objects were collected.

Although the project used the best available technology and has produced object records that provide significant new information over and above photographs used in current museum practice, it became clear that for 3D colour scans to be of real use to the museum and conservation specialists a higher specification is needed. This involves higher resolution, better rendition of colour, reflectivity and texture. Another requirement is the ability to combine several different types of image data in order to allow for more detailed examination and comparison of discrete areas of interest. The issues of accuracy and reliability of 3D records came forth during the processing and editing of the captured data and demonstrated the importance of track-recording the changes made. To make a 3D model a convincing and efficient knowledge base, we need to carefully meet the requirements identified, especially geometry and colour.

Despite the lack of previous experience of dealing with scan data and metadata, curators and conservators intuitively navigating the 3D model and were very ready to engage with the potential of the technology and keen to see it developed further.

Further development, based on user interface design and iterative local and remote user testing, will be conducted to improve the functionality of the existing E-Curator prototype.

The next section of this paper describes work in progress to build upon this interdisciplinary collaboration in order to progress best practice in the 3D colour recording of museum artefacts.

3.3 Methods and evidence to generate best practice

To assess 3D imaging of museum objects from an engineering point of view comparative imaging will produce numerical evidence (same museum object and /or calibration objects, different sensors). The following parameters will be taken into account: resolution, accuracy, noise, colour fidelity, data processing chain, while producing **quantitative and qualitative evidence of geometry**. Non-contact nominal/actual value comparison, Hausdorff distance filtering, volume measurements of data sets will be undertaken and results plotted into a comparison graph. These tests will help to compile a classification of sensors with their capabilities. (Beraldin 2009) and (Remondino 2007) have suggested methods to produce scientific evaluation of sensor resolution and accuracy.

To test **colour fidelity** of the sensors a full scale or small scale Gretag Macbeth Chart is used as standard. It consists of 24 scientifically prepared coloured squares, with a lambertian surface, including bright white and dark black. A comparison will be produced to evaluate the colour recording consistency of differing imaging methods.

Recommendations for a defined **post-processing chain** from 3D scan to final model will be given to ensure geometric consistency.

A wealth of current projects will be used to inform a **user survey of conservators and curators** in order to collect information about the use of 3D digital images in museums and collections and their current implementation in the daily workflow.

The development of a decision tree for cultural heritage professionals largely depends on the **analysis of taxonomies and terminologies** used by those disciplines involved. (conservators, curators, engineers, computer graphics) to guarantee a common semantics.

Decision making science, for example an analytical hierarchy process, will help to develop an interface for the input of criteria on the side of the CH professional.

A **decision tree** will be developed to plan and predict results in order to suggest one or more imaging methods to answer specific questions. Beginning with a conservation question about a specific object with its very own 'fingerprint' the interface would let the museum professional define a documentation goal (see Table 2). After certain criteria are input, based on the classification of imaging sensors, the entries are evaluated and in the end recommendations for imaging tactics are made. Iterative user testing and constant sensor information updating will enable the improvement of the decision tree.

object	surface features, material, size, condition
objective(s)	conservation question, digital documentation, exact metric measurement/ object geometry, identify/ quantify damage, monitoring/ comparison, multimedia representation, replica
criteria	sensor portability, resolution, colour (fidelity) metric accuracy, data output
choices	combination of one or more imaging sensors: active and passive measurement methods, conservation science analyses, conservation imaging

Table 2 Decision making process based on object information, objectives and criteria

The final objective of this ongoing research is the development of a **best practice guideline** so that CH professionals can specify their aims, turn to the right technologies, and understand and evaluate them with regard to their museum documentation tasks. Definitions for viewing and lighting conditions with a calibrated monitor for a persuasive and informative presentation of a 3D surrogate of a museum object will be investigated.

4. CONCLUSIONS

The driving process in 3D colour museum object recording is to leverage the right communication and technology transfer between imaging technologist and CH professional, as well the development of convincing and feasible best-practice recommendations to ensure high-quality models, optimal presentations and viewing conditions. A series of very detailed recommendations have already been delivered by the EPOCH Research Agenda (Arnold & Geser 2008).

Systematic errors of recording systems, for example intrinsic uncertainty (Beraldin 2009, sec.3.1) and range artefacts (F Blais et al. 2008, p.4) must be clearly explained to the end user to avoid erroneous interpretation of imaging results.

Clear definitions of deliverables and specifications for a museum object record and 3D model need to be agreed upon before recording starts. The scope of recording needs to be clear from the onset to assure that choice of sensors, settings and subsequent processing will be successful.

Strikingly the common answer for the exigencies of a highly convincing 3D object was geometry, but much more critically – high-fidelity colour information. To bring both criteria for a high-quality 3D surrogate together in a metric manner whilst presenting them in a user-friendly environment, would not surprisingly have great impact on the museum community.

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