Innovating Cultural Heritage: Modified Smartphone Multispectral Imaging for the Pigment Analysis of Roman Egyptian Soter Shrouds

Rachel Coderre, Sean Billups, Phil Parkes, Kenneth Griffin

INTRODUCTION

This research focuses on a collection of 28 fragmentary funerary shrouds and two cartonnage pieces from Thebes, Egypt. These artifacts, known as the Soter shrouds, date to the 2nd century A.D. and represent a significant example of Roman Egyptian funerary practices. This study employed modified smartphone multispectral imaging techniques to explore the pigment compositions and workshop techniques utilized in these textiles, revealing previously unseen details and offering a deeper understanding of their production and cultural context.

Multispectral Imaging (MSI) is a powerful analytical tool used in cultural heritage conservation, though traditional setups are often prohibitively expensive and inaccessible to smaller institutions and conservators. The use of a MSI system based on a modified smartphone provides a cost-effective, portable alternative. This technology retains the capabilities of traditional MSI techniques while making advanced imaging more accessible.

This collaboration highlights the potential for innovative and accessible technologies to drive advancements in cultural heritage research. By expanding the use of MSI into under-explored areas, we aim to make previously inaccessible analytical tools more widely available. A smartphone-based imaging system presents an attractive option for institutions and private practices seeking to maximize impact with limited resources. Beyond advancing our understanding of Roman Egyptian funerary textiles, this work paves the way for future research, utilizing affordable, innovative techniques that push the boundaries of traditional research methods.

METHODS

A Pixel 3a smartphone was modified by removing the internal IR/UV cut filter (hot mirror) and replacing it with unfiltered glass. The filters used were IR 850nm: R85 IR850nm longpass from Green. L, UV 365nm: ZWB2 UV pass filter from Nantong Foric Optical Glass Factory Store, and Visible bandpass: BCF UV IR Cut for astronomy (400-700nm). The handheld lights were IR850: Andoer IR49S Mini IR from "3C High-tech Store" and UV light in a photo studio. The variable color was RCL01 RGB Video Light from "lewinner."

The imaging techniques employed for the shrouds are detailed in the table below.

MSI Technique, Filter, and Illumination Source Used

MSI Technique	*Filters*	*Light Source*
Reflected Ultraviolet (UVR)	UV 365nm bandpass filter	UV 365nm light
Ultraviolet-Induced Visible Fluorescence (UVF)	Visible bandpass filter	UV 365nm light
Visible light (VIS)	Visible bandpass BCF UV IR cut for astronomy (400-700nm)	Studio lights
Visible-Induced Infrared Luminescence (VIL)	IR850 filter	RCL01 RGB (2000mAh) LED, red excitation
Reflected Infrared (IRR)	IR 850 nm longpass filter	Andoer IR495 Mini IR 850 light
Visible Induced Visible Luminescence (VIVL)	Visible bandpass BCF UV IR Cut for astronomy (400-700nm) + Hoya O(g) orange filter 58mm	RCL01 RGB Video Light from "Lewinner", green excitation
Multiband Reflectance Subtraction (MBRS)	400-650nm visible bandpass filter + 680mn longpass filer + additional image using 735nm using a 365nm UV bandpass filter	Lewinner RCL01 RGB (2000mAh) adjustable LED, red excitation + additional image using 740nm IR light source

Figure 1: Table detailing MSI techniques used.

Figure 2: Modified Pixel 3a smartphone and components used for the multi-spectral imaging of this study.

Multi-Spectral Imaging Techniques for Each Object

Object	Description	MSI techniques
EC38	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC115	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC116	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC117	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC118	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC119	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC120	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC121	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, VIVL
EC131	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC163	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC165	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, VIVL
EC166	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC167	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC169	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC170	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC171	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC172	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC173	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC174	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC175	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, VIVL
EC176	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, VIVL
EC177	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, VIVL
EC185	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, VIVL
EC5971	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
EC5972	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR
W870	Cartonnage	VIS, UVF, UVR, VIL, IRR, FCIR
W945	Cartonnage	VIS, UVF, UVR, VIL, IRR, FCIR
W1027	Shroud	VIS, UVF, UVR, VIL, IRR, FCIR, MBRS
W1039	Shroud	VIS, UVF, IRR, VIVL

Figure 3: Table detailing MSI techniques used per object analyzed.

RESULTS

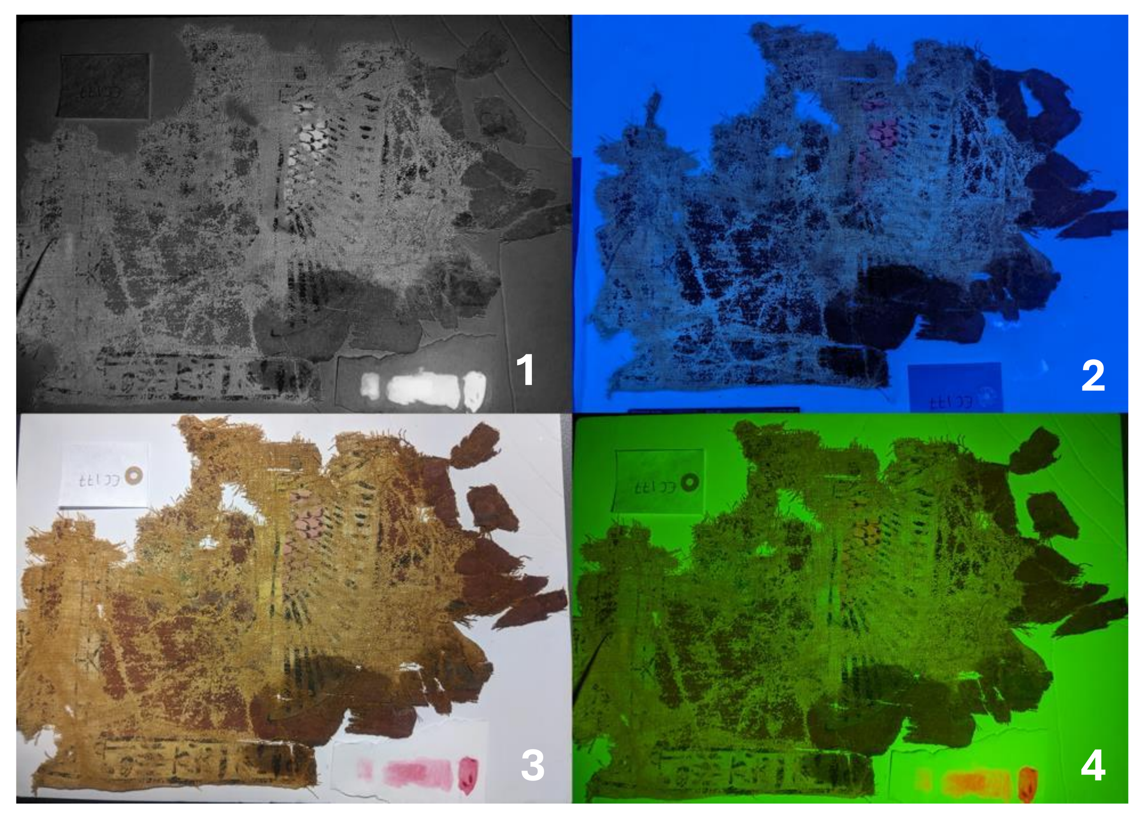

Figure 4: shroud EC177 images of 1: red channel only VIVL, 2: UVF, 3: VIS, and 4: VIVL. For identification of madder lake pigments Visible-induced Visible Fluorescence was employed, with green light excitation and a combination of long and short-pass filters to capture a bandpass image around 650nm.

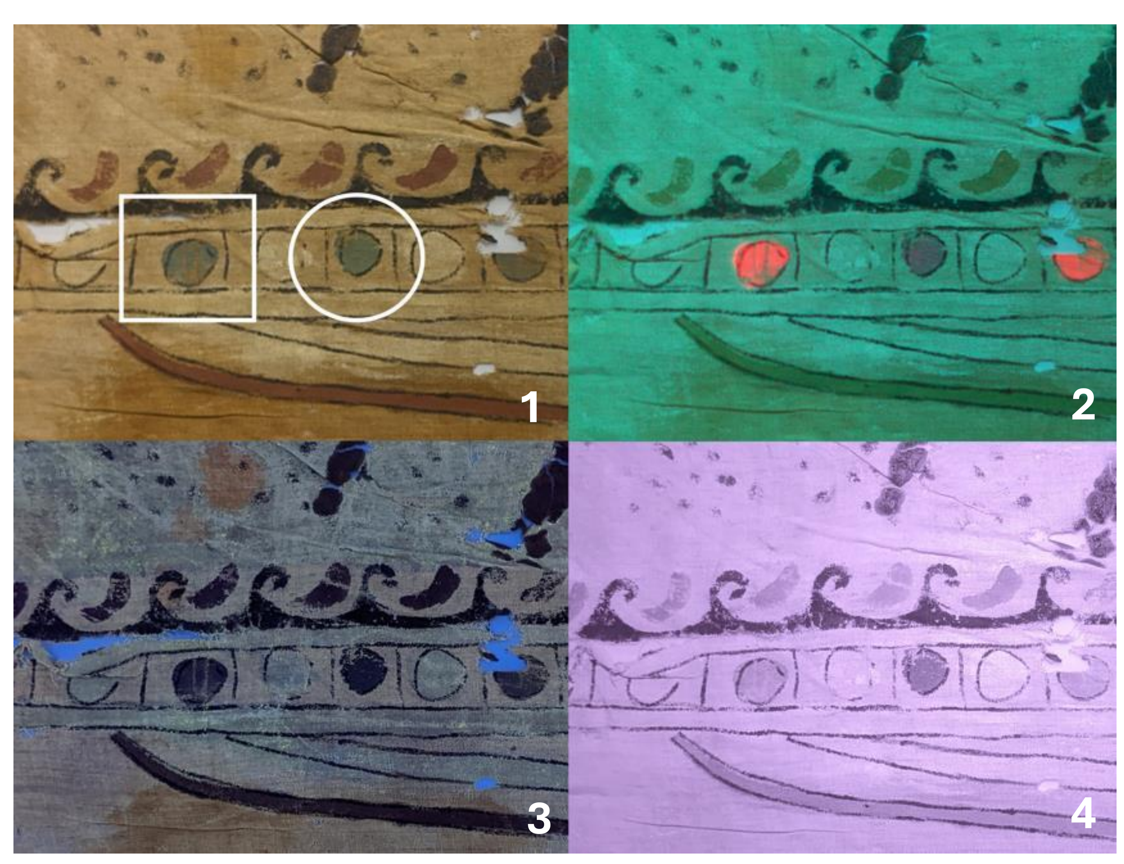

Figure 5: EC115 under 1: VIS, 2: FCIR, 3: UVF, and 4: IRR. The luminescence of Egyptian blue (square) and partial luminescence of 'secondary blue' (circle) can be seen under FCIR (top right). This suggests possible ancient reuse, overpainting, or mixing of Egyptian blue with other pigments. Egyptian blues have been found in mixtures to enhance the brightness of other pigments during the Roman period (Siddall, 2006).

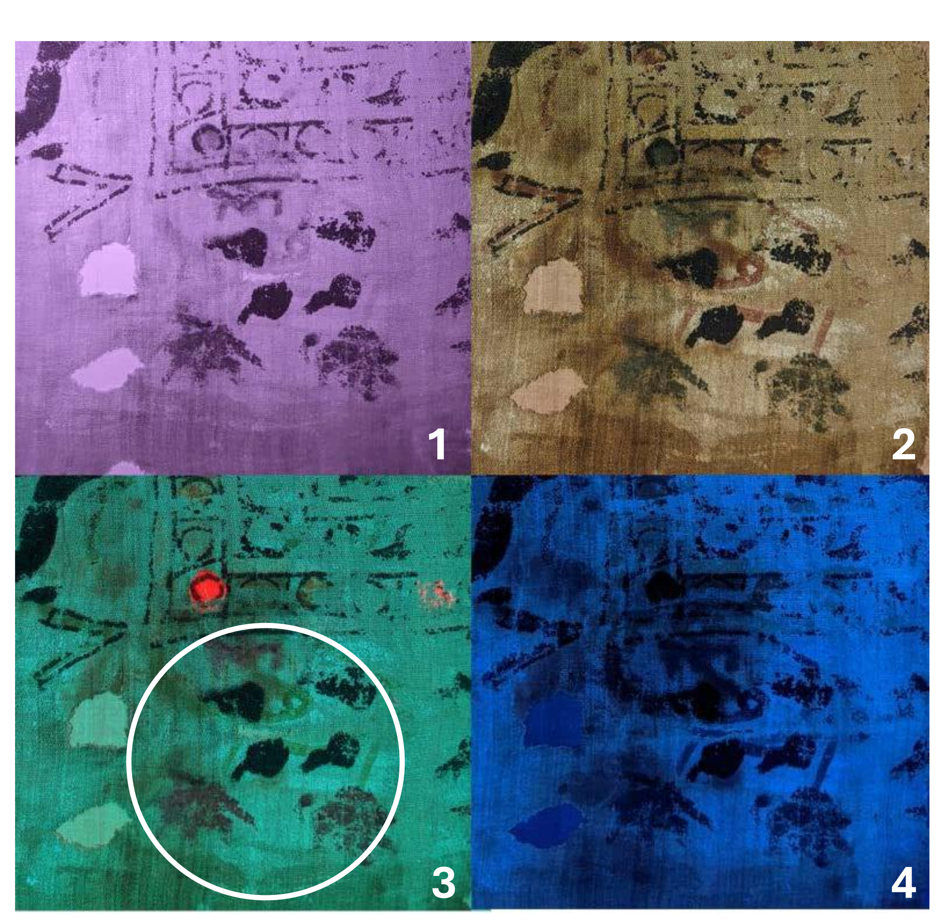

Figure 6: W1027 under MRBS, VIS, FCIR and UVF imaging techniques. MRBS was explicitly utilized to rule out the presence of indigo. According to a study from Dyer and Newman (2020), indigo is known to appear as bright red under FCIR, and the bottom left image shows a partial red appearance (circle). This led to the use of MBRS, which ultimately did not point to the use of indigo. If indigo were present, it should have appeared as bright white (top left).

DISCUSSION

Figure 7: A similar pattern has been observed in EC5971 and EC171, supported by visual and multispectral imaging (MSI) results. These objects have been combined to illustrate the patterning parallels. Notably, under FCIR processing, a faint, irregularly shaped dotting pattern of Egyptian blue can be detected along the shroud's border—dots that are nearly invisible to the naked eye. This continuity suggests that these fragments may have originated from the same shroud or been produced by a similar workshop or artisans. However, certain differences challenge this hypothesis. For example, the curvature of the black wave pattern on EC5971 contrasts with the opposite curvature seen in EC171.

Figure 8: Two shroud (EC170 and EC115) fragments digitally stitched depicting the lower part of a Soter style shroud (sandaled feet framed by black jackals). The Pb-based pink dots emit a pronounced glow under FCIR, an effect not observed in other shrouds with Pb-based pinks (notated in squares). This could indicate similar pigment mixtures for the blues and pinks used in both fragments, suggesting a common workshop or source for their production.

Pigment studies of Soter group shrouds

Museum	Object	Century	Methods	Colours	Pigments
Museo Civico Archeologico (2024)	MCABo EG 1974	1st-2nd century C.E.	FTIR, HPLC/MS, GC/MS, OM, SEM/EDS	White, orange-red, red-brown, dark red, pink, yellow, blue, black	Egyptian blue, Egyptian green, calcite white, red lead, red ochre, madder, unknown organic yellow dye, carbon black
Fitzwilliam Museum, Cambridge (1992)	E.GA.5.1943	200 CE - 300 CE	Unspecified elemental analysis, OM		Carbon black, unidentified organic pink, red ochre, brown ochre, yellow ochre, Cu containing green
British Museum (1984)	68950	Late 1st – early 2nd century C.E.	OM, microchemical testing, furfural test, saponification	Black, pink, green, yellow, brightest blue, brick red, red	Charcoal black, carbon black, lake pigment, unidentified yellow, Egyptian blue, green earth, red lead, red ochre
Egypt Centre (2024)	EC38, 115, 116, 117, 118, 119, 120, 121, 131, 163, 165, 166, 167, 169, 170, 171, 172, 173, 174, 175, 176, 177, 185, 5971, 5972, *W870, W945*, W1027, W1039	2nd century C.E.	MSI, pXRF, PLM	Black, red, blue, pink, yellow, orange, green, white, *brown, grey/discolouration, purple, inpaint*	Carbon black, red lead, red ochre, Cu blue, Cu green, madder lake, calcium based white, green earth, orpiment

Figure 9: Additional analyses of the pigments noted in these studies could yield further comparative insights. This table intentionally focuses on shroud analysis rather than broader Soter group coffins, etc., to exclusively focus on shroud-specific information.

CONCLUSIONS

Subtle patterning and pigment application similarities across shroud fragments suggest standard production methods, possibly involving multiple workshops. Further investigation into the connections between fragments such as EC170, EC115 as well as EC5971, and EC171 could provide crucial insights into workshops associated with Roman Egyptian funerary textiles. The similarity between EC170 and EC115 could indicate similar pigment mixtures for the blues and pinks used, suggesting a common workshop or source for their production. The consistent pigment behavior and decorative features strongly suggest a connection between the fragments.

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