

Pixels and Parchment: The Application of RTI and Infrared Imaging to the Dead Sea Scrolls

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The Dead Sea Scrolls, one of the most important archaeological discoveries of the twentieth century, are in constant need of conservation and restoration. An ongoing research project being carried out at the paper conservation laboratory of the Israel Museum Jerusalem is applying the combined potentials of Reflectance Transmission and Infrared imaging to deteriorating fragments of one of the most badly damaged Scrolls. Early tests show that both infrared imaging and RTI imaging have a lot to offer the conservation process, the one offering surface penetration information and the other surface texture analysis. However, it is the fusion of the two technologies together which holds the promise of a unique insight into the “surface beneath the surface”. This technique, while showing great promise, is still in its early stages of testing and definitive conclusions are as of yet not possible.

*Reflectance transmission imaging. Polynomial texture mapping. Infrared. Dead Sea Scrolls.
Image processing, Paper conservation.*

1. INTRODUCTION

The Israel museum in Jerusalem, Israel was established in 1965 as a vision of the former Mayor of Jerusalem Mr. Teddy Kolek. The museum is a non-profit organization and is considered to be the national museum. Its collections contain nearly 500,000 items, making it Israel's leading cultural institution and one of the leading encyclopaedic

museums of the world. Such vast and rare collections require constant monitoring and stabilizing and this is done by highly professional teams of six conservation laboratories: Chemistry, Objects, Paper, Painting, Textile and Wood Conservation.



Figure 1: The Shrine of the Book, Israel Museum, Jerusalem

One third of the Museum collection is comprised of paper and parchment based materials. These include prints and drawings of modern and contemporary artists, 19th century photographic

images, Old Masters drawings, medieval Jewish manuscripts, and the jewel in the crown, the Dead Sea Scrolls. One of the most important archaeological discoveries of the twentieth century

and amongst the earliest written documents on earth.

2. THE DEAD SEA SCROLLS

Housed in a specially built wing named the Shrine of the Book (see photo above), the Dead Sea Scrolls are dated between the third century BCE and the first century CE. The first seven scrolls were chanced upon by a Bedouin boy in 1947, whilst following a wayward sheep into a cave in Qumran, situated in the Judean desert, north of the Dead Sea shores. Over the subsequent nine years tens of thousands of further scroll fragments were uncovered. The majority of the scrolls were written in Hebrew. Others were written in Aramaic and old Greek. Likewise, Most of the scrolls are written on parchment, primarily goat skin, though some texts are on papyrus. Biblical researchers believe that the 30,000 fragments uncovered belong to some 850 scrolls (Roitman 2006). The texts fall into three main categories: Biblical, apocryphal and sectarian. The discovery of the Dead Sea Scrolls marked a turning point in the modern study of the history of The Jewish people in ancient times. For never before has a literary treasure of such magnitude come to light. The scrolls Reveal the Jewish life in the land of Israel during the Hellenistic and Roman period, as well as the origins of Rabbinical Judaism and early Christianity (Eshel 2006).

3. CONSERVATION OF THE SCROLLS

Since the Shrine of the Book became the site of the Dead Sea Scrolls, the conservation effort for preservation of these important documents was initiated as well. The concept behind the conservation of the scrolls is that of stabilization and prevention. it can be compared to the simple logic behind the structure of an onion, in which the outer layers protect the inner ones.

Such a concept is similar to the approach of modern medicine which advocates that the environment has a crucial effect on mankind's health. Therefore, much effort was invested in creating what we believe are ideal surroundings for the Dead Sea Scrolls. The facts that the scrolls survived in relatively good condition for more than 2000 years in a dark and dry cave strongly supports this preventive environment philosophy.

Thus, the Dead Sea Scroll's environment while on display or in storage are constantly monitored to meet the following stable conditions: The scrolls are displayed for a maximum of ninety days throughout the year. Light is restricted to 30 lux (free of UV), temperature: 19° degrees Celsius, relative humidity 47% (Magen 2008).

The fragments are all matted in special cases which contains a few layers of acid free board. The fragments are housed between two layers of thin and transparent polyester mesh. These are then embedded between two sheets of transparent polycarbonate.

As stated, the conservation process is primarily passive and centred around stabilization and prevention of further deterioration. To this purpose the scrolls are checked on a regular basis in order to maintain a strict control of their physical state. Photographic records are used both for visual comparison and for evaluation of their day to day condition.

More sophisticated digital imaging methods are presently being adopted and are currently undergoing preparation (Bearman 1998). Most notable amongst these is the Google / Dead Sea Scrolls Collaboration, initiated by the IAA (2010).

The Israel Antiques Authority which oversees the care of the scrolls, has embarked on this monumental undertaking, involving high resolution, multispectral imaging of the entire corpus of the thirty thousand fragments.

This task, which is expected to take some 2-3 years, will ultimately link together all the images to a vast database of academic research which has amassed over the past several decades. The results will be uploaded by courtesy of Google and made available to the world at large. The project is driven primarily by the need to record and preserve the information on the scrolls, before any further deterioration takes place, as well as by the desire to make the scrolls accessible to the entire world, Laymen and researchers alike.

It was in preparation for this project that the idea was raised that perhaps RTI imaging could also be of use in aiding the conservation process, primarily in offering detailed surface texture information for long term comparisons.

With this in mind it was decided to focus on several scroll fragments and test empirically what RTI has to offer the paper conservation specialists, both on its own, and in conjunction with near IR photography.

One must acknowledge that this is not altogether the first case of RTI imaging of Dead Sea Scroll fragments. In 2009, Bruce Zuckerman, professor of religion and linguistics at the West Semitic Research Project (WSRP) and USC College, performed the first PTM images, on several Dead Sea Scrolls fragments kept at St. Mark's Syrian Orthodox Cathedral in New Jersey (Zuckerman 2010).

4. PTM - RTI

Before moving on to describe the nature of this project, a few short words about Reflectance Transmission Imaging is required.

RTI is a unique digital photographic technique aimed at enhancing the surface detail of objects through an algorithmic combination of multiple registered digital images of the object, shot with controlled, varying, yet known light positions.

Originally termed Polynomial Texture Mapping (PTM), the technique was invented by Tom Malzbender at the Hewlett Packard Labs. The seminal paper describing the method was published in 2001 (Malzbender *et al.* 2001).

This paper does not propose to describe the RTI method itself. Articles explaining RTI and PTM are numerous, as too are those outlining its uses.

Rather, the emphasis here is on describing the application of RTI to the perspective of paper conservation, as well as of the accumulative process of discovery through the combined surface penetration (IR) and surface enhancement (RTI) methodologies.

5. STRUCTURE OF THE SCROLLS

The Dead Sea scrolls were written mainly in carbon-based ink on parchment, most likely from goat skins. Subsequently, due to the passage of time, climatic and desert conditions, vast portions of the scrolls and numerous scroll fragments are either indecipherable or entirely invisible to the naked eye or to conventional photography (Roitman 2008).

The aim of our project was to (non intrusively) penetrate the encrustation to the damaged surface of the scrolls, to reveal the hidden texts underneath and at the same time analyze the surface condition of the underlying parchment with an aim at offering localized suggestions to its conservation and possible restoration.

6. FRAGMENT CHOICE

For our ongoing research it was decided to explore the surface of one of the oldest documents on earth, the Genesis Apocryphon (Column 12-13), which is in an extremely fragile and sensitive state due to its deteriorated stage.

The Genesis Apocryphon was written in Aramaic and consists of four sheets. It is named after its content, which retells parts of the Biblical book of Genesis, largely in the first person. The document

records a conversation between the biblical figure Lemech, son of Methuselah, and his son, Noah (Eshel 2006). Originally called the Apocalypse of Lemech, the Genesis Apocryphon is one of the original seven Dead Sea Scrolls. It is also the least well preserved, hence its choice for our purpose.

The reason for its poor condition is probably because the seal of the jar in which the scroll was stored was broken (Figure 2).



Figure 2: Prof. Biberkraute examining the Genesis Apocryphon scroll. Early 1950s

Prof. Biberkraute, the first conservator of the scrolls suggested to Prof. Yigael Yadin the archaeologist who discovered them to not interfere with it by any form of conservation intervention, since the scroll was in too delicate a state. Thirty years after the discovery of the scroll some of the fragments showed such an advanced state of deterioration (Figure 3) that there was a need to stabilize them by adding extra lining supports from various materials, mainly new parchment clips and thick Japanese paper.

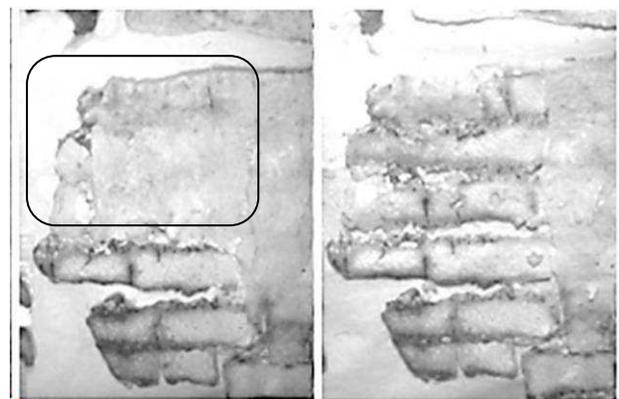


Figure 3: Deterioration of Apocryphon. Late 70s

Today we know that part of the relatively rapid damage was as a consequence of the lack of climate control where the scrolls were displayed and deposited. During the end of the last millennium a fragment of the Apocryphon was subject to conservation intervention by the author of this paper at the paper conservation laboratory of the Israel Museum. The old previous linings were removed and a better backing support method replaced the old ones. Part of the packing layers which had deteriorated probably adhered to the flesh side of the parchment, masking the written text (Figure 4). Therefore, parts of the masking layers were removed with the aid of a digital infrared video cameraⁱ, revealing hidden text below. The use of infra-red video contributed to the amount of control needed for such delicate conservation intervention.



Figure 4: RGB and Infrared comparison

This fragment, like many of the GA fragments is in an advanced “gelatinization” stage. Gelatinization is a term used by scientists and conservators to describe collagen fibre deterioration and it is associated with dehydration and heat effects on parchment and other skin products (Reed 1972). Parchment which has suffered the gelatinization process is subject to colour changes, brittleness, loss of flexibility loss of strength and deformation. Part of these physical effects characterizes the surface and in advanced stages such as ours they cause the text to become illegible to the naked eye. Furthermore and worse still, they also prevent the conservator from assessing the parchment condition state. This was the reasoning behind the use of infrared and RTI imaging.

The GA scroll contains 19 columns, all of them in an advanced state of deterioration. This, in addition to their sensitive physical condition leaves less than ten percent legible to the human eye. The rest of the text has become invisible, as the black ink has blended with the parchment's dark colour. Near infrared, between 750 – 1000 nm. is the only way to read this ancient text. The purpose set out in this research was to gauge to what extent Infrared RTI imaging would allow the researcher to interpolate the image between shades of light and dark, thus

revealing and distinguishing the surface texture and the text within it, a task which could not be achieved with the conventional infrared imaging.

7. SEPARATE INFRARED AND RTI IMAGING

Therefore, in conjunction with scroll expert and researcher, Dr. Ester Eshel, and the Shrine of the Book director, Dr. Adolfo Roitman, several especially damaged fragments were chosen.

The initial stage of tests involved standard Infra Red imaging to reveal what lay beneath the jellified parchment surface (Figure 5).

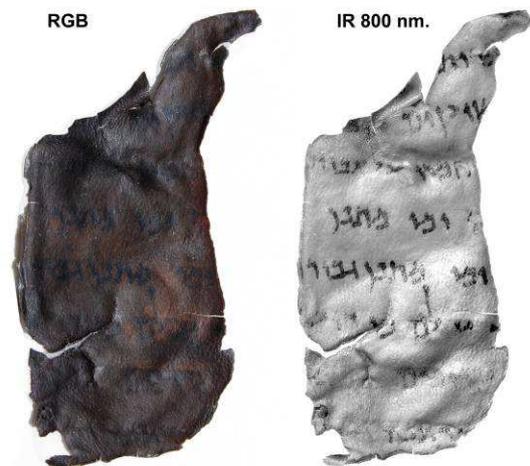


Figure 5: Fragment of the Hodayot Scroll. Left: RGB. Right: Infrared 800nm

The images were taken with a modified Nikon DSLR, from which the infrared blocking filter had been removed. Such removal can be performed by digital infrared conversion services. However, with a basic knowledge of camera mechanics this can also be performed in house. Several sets of calibrated images were taken through four different wavelengths: 750 nm, 800 nm, 1000 nm and 1200 nm. (Figure 6)

The test images immediately showed that The CCD image sensor which is fabricated in silicon has a cut-off wavelength of around 1100 nm. Hence, the 1200 nm images yielded no results. Comparison of the three remaining images showed little difference in penetrability, however, the 800nm. was determined to give the best results on the parchment and the ancient texts rose brilliantly out of 2000 years of darkness.

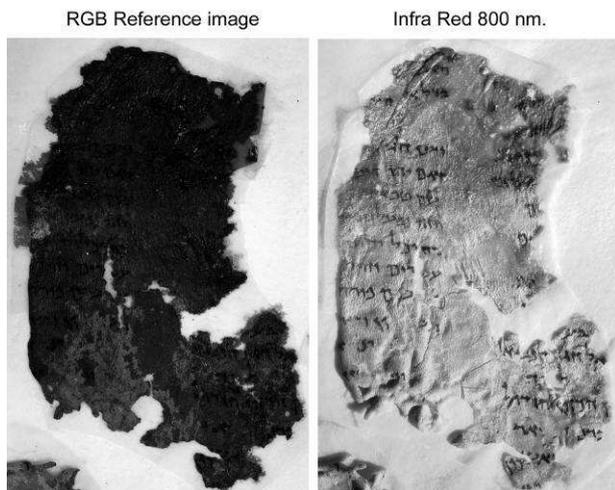


Figure 6: Fragment from the Genesis Apocryphon.
Left: RGB, Right: Infrared 800nm

Next, a series of RTI images were taken, using conventional flash light with the UV wavelength filtered out, to protect the parchment.

The RTI images were initially taken using the black ball highlight method. For this method, a glossy black globe of approximately 2 cm. in diameter was used. The setup involved a Nikon DSLR fixed on a copy-stand and a portable flash rigged to a revolving arc. This enabled both easy and relatively precise controllable shooting.

For comparison, it was decided to shoot some RTIs using the dome method. The RTI dome, currently under construction consists of a semi hemispherical black Perspex dome 1 meter in diameter, into which 50 symmetrically aligned holes are drilled. These are then plugged with LED lights, wired together to an Arduino board relay system, allowing the LEDs to be fired in succession and in sync with the camera.

Whilst tests so far have not shown any noticeable differences between the quality of the highlight and the dome methods, it has nevertheless been decided that all further tests will be carried out using the dome method. This is both faster, and also offers very precisely repeatable results.

Test RTI images were again encouraging (Figure 7). Beyond the expected yet at the same time fantastic surface textures, decipherable under the infinite lighting positions and filtrations, important information was viewable regarding the jellification and cracking of the parchment. However, the surface information gleaned by the RTI images on their own was not enough, as much of the information lay hidden beneath 2 millennia of physical and organic deterioration. Thus, it was decided to see if the combination of RTI together with infra red imaging could yield greater insight

into the conservation analysis process, as well as suggest new methods for the ongoing research and deciphering of the fragments themselves.

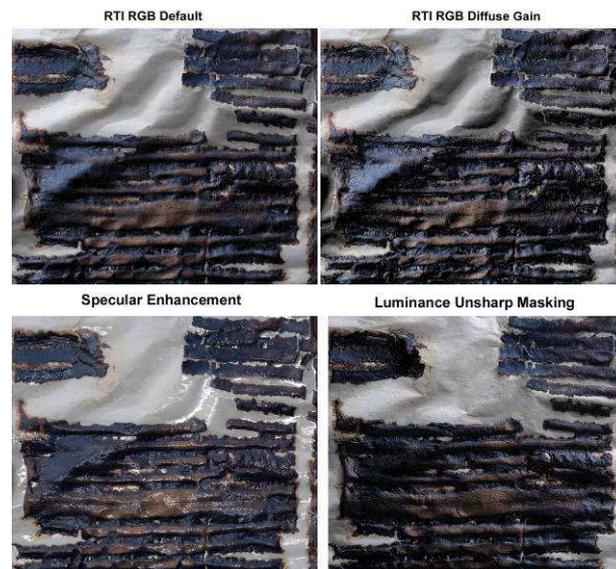


Figure 7: RGB RTI of the Genesis Apocryphon showing the effect of four different settings (left to right): Default lighting, Diffuse Gain, Specular Enhancement, Luminance Unsharp Masking

8. COMBINED INFRARED AND RTI IMAGING

Infrared RTI imagery is a totally new technique, never before performed on the Dead Sea Scrolls. The declared aim is to explore the "surface beneath the surface", to look critically at the texture and condition of the parchment which is hidden to the naked eye.

This process involved the construction of an RTI system based on simple consumer electronic flash lights, rich in IR output. The same Nikon DSLR as before was used with a Micro Nikkor 55 mm lens and an 800nm. IR filter.

Once again, results of early infrared RTI tests are encouraging (Figure 8).

The images here represent just a drop in the ocean of possibilities for endless best selection. The following close-up image from the Apocryphon (Figure 9) reveals the topographical structure of a gelatinized parchment. This image which is composed of two units demonstrates the "mountains & valleys" of deteriorated areas where the collagen fibres withdraw from the text areas, probably as a result of the ink's corrosion.

The colour of the conventional RGB image on the right fails to represent these effects to the same extent as in the left image which is shown in the RTI specular mode. The specular option in the RTI

software is one of several imaging interpolation enhancements. It is particularly effective in that it removes the colour and increases the mirror like reflective quality of the surface, thus clearly bringing out the topography of the surface and the effects of the gelatinization.

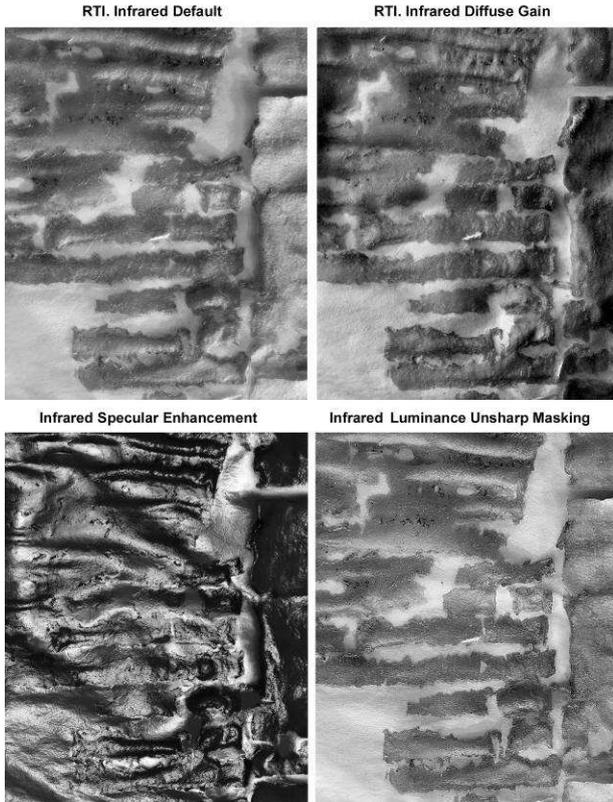


Figure 8: Infrared RTI of the Genesis Apocryphon showing the effect of four different settings (left to right): Default lighting, Diffuse Gain, Specular Enhancement, Luminance Unsharp Masking



Figure 9: Conventional RGB on the right. Specular enhanced RTI on the left

Early tests represented here (Figure 10) clearly show the combined effects of infrared and RTI imaging with specular enhancement and diffuse gain on an extreme close up of the parchment, totally unseen to the normal eye.

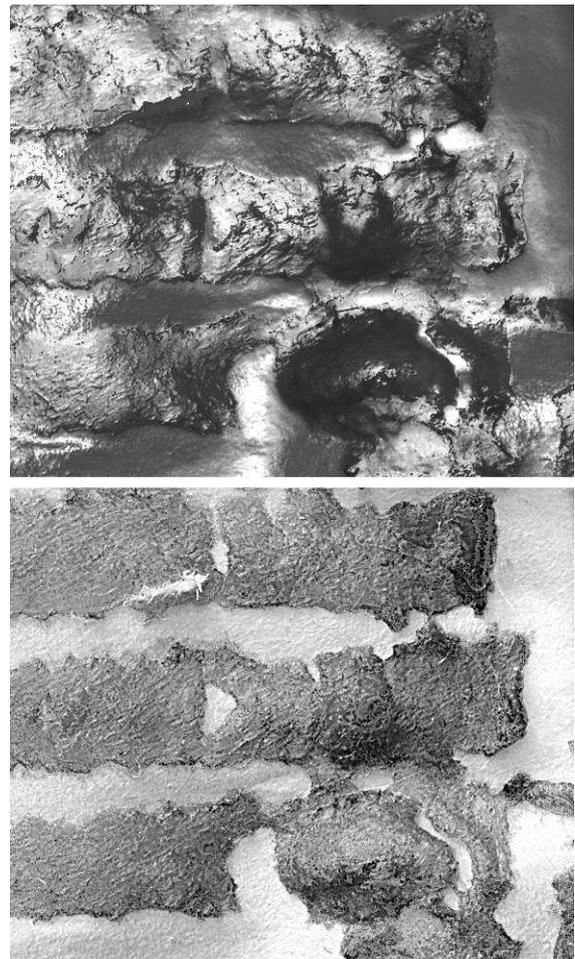


Figure 10: Extreme close up infrared RTI. Top: specular enhancement. Bottom: Diffuse Gain

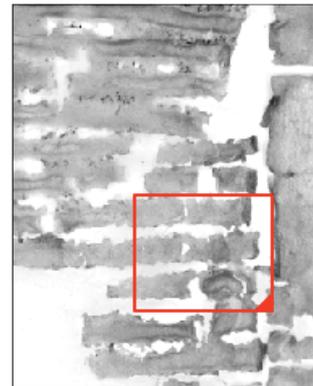


Figure 11: Overview of fragment section showing area of close up RTI images

9. CONCLUSIONS

New technologies such as Reflectance Transmission Imaging (RTI) are providing a new dimension to image enhancement and their adaptation to conservation is increasing our abilities to visualize the artifacts in a way that was not seen before. The RTI image greatly increases the conservator's ability to learn, evaluate and suggest possible

conservation interventions to stabilize the target artefact.

However, the combined effects of IR and RTI imaging need to be further explored with regard to the new finds and more research still needs to be carried out in order to interpret the full meaning of the image data to the scroll's condition.

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