

# Combination of Full-Range SWIR Hyperspectral Imaging and Multivariate Curve Resolution (MCR) in Non-Destructive Analysis of an Early Flemish Painting

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## Abstract

A small panel painting in the Virginia Museum of Fine Arts (VMFA), Christ Appearing to the Virgin, executed by an unknown Flemish artist in 1520 was examined using hyperspectral imaging (HSI) equipment. The purpose of this ongoing evaluation is to study the underdrawing and painting materials with the hope of identifying the artist of VMFA's work by comparing the results to underdrawings and materials in paintings by known Flemish artists of the same period. [Virginia Museum of Fine Arts, Gift of Robert Lehman. Oil on panel; 23.5 in H x 9.5 in W; Acc. # 45.36.1]

The early Flemish painting was examined using 1000-2500 nm hyperspectral imaging. The data shows that this wavelength range can reveal both the underdrawings and the chemical composition of the paint layers. The use of Multivariate Curve Resolution (MCR) allows the separation of the different components as they appear in cultural heritage objects. In the case of the Flemish painting, several important observations were made that would not be possible without the combination of SWIR hyperspectral imaging and MCR. The dramatically reduced details of the drapery of the virgin compared to the underdrawing may be explained by altered artistic priorities before concluding the work or may reflect a later cover or repair. Whilst the explanation will be left to the art historians, the chemical analytical data provided by MCR offers important information beyond standard infrared reflectograms. A small, invisible crack or mark can also be visualized in one of the MCR components.

## Background

Tools of instrumental analytical chemistry and experimental physics are used to reveal the age, composition, history, authenticity and other important characteristics of cultural heritage objects of all kinds. For old master paintings many techniques have been found to be useful, such as visible and Fourier transform infrared (FTIR) spectroscopy, infrared microscopy, X-ray radiography, pulsed X-ray fluorescence (pXRF), polarized light microscopy (PLM), SEM-EDS 1. Near infrared imaging with a simple camera, using the 1000-1700 nm region, for example, was known from the 1960s and was dubbed as infrared reflectography (IRR) 2 and was widely used in the conservation, cultural and art evaluation fields.

Hyperspectral imaging combined with multivariate analysis techniques, such as multivariate curve resolution (MCR)<sup>3-4</sup>, has proven to be a powerful imaging tool for understanding many complex samples in life sciences, aerospace and other industrial manufacturing, geology and other technical fields. The 1000-2500 nm wavelength region is particularly suitable for examining oil paintings. The near-infrared light is able to penetrate the top layers and reflect back from prior paint layers, underpainting and imprimatura. Depending on the wavelengths used, the thickness, absorption and scattering characteristics of the paints, solvents and additives, the underlying characteristics and images become visible.

Having hundreds of spectral data points available at each spatial point on the painting allows information to be obtained that is not available using IRR, which is basically a monochrome image with a single light intensity at each location. Due to the fact that the different wavelengths carry different information (e.g. chemical information), the wavelength information can be combined to gain much more information. Some paints have known spectral signatures that can be identified, others are diluted with different solvents and oils, yet others are mixed by the paint manufacturers or the artists as it was done in the era of the painting (current investigation). This is why it is important to first be able to discover the spectral signatures varying within a work of art and then apply this knowledge to gain the new information about the painting. Multivariate curve resolution is an iterative least squares spectral fitting technique that discovers all the independently varying spectral signatures present in the hyperspectral images and quantifies the amount of each signature for each pixel in the image<sup>3-4</sup>.

## Hyperspectral Data Source

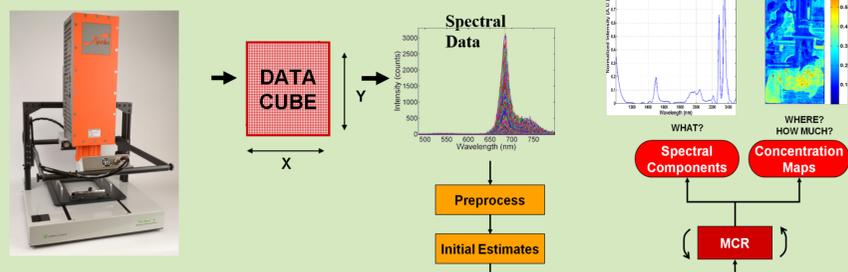


Figure 1. Block diagram of Multivariate Curve Resolution (MCR)

## Experiment

A six-foot long linear scanner combined with support electronics and a hyperspectral SWIR camera (980 nm-2550 nm, Specim Ltd, Oulu, Finland) having a Stirling cycle cooled mercury-cadmium-telluride (MCT) detector, was used for the measurements. A Dual 4 x 20W Halogen Line-Light (MRC-920-025, Middleton Spectral Vision, Middleton WI) was providing the moderate intensity broad band illumination.



Figure 2. Measurement with horizontal camera setting.

Effects of illumination on the painting was periodically tested during the scanning with a non-contact thermometer to assure that the exposure to the lamps was not causing heating of the painting, especially in the darker areas.

The art piece was placed in a vertical position on an adjustable studio easel and scanned along its long axis in three bands with substantial overlap. The painting, for this particular work, was chosen to be scanned in about 4" swaths which amounted to about 250 um spatial resolution.

The raw data was corrected with dark and white readings from the SWIR camera using the same frame rate, integration time and the same optical arrangement using a polytetrafluoroethylene (PTFE) standard surface in the same position as the painting. The three swaths scanned were seamlessly combined into one file, therefore all enclosed images are shown here as one full entity.

The fast and memory-efficient MCR algorithm is an integral part of the KemoQuant™ software (developed by Middleton Spectral Vision, Middleton WI) that was used for the analysis of the hyperspectral image data.

## Results

An early Flemish painting by an unknown artist was scanned on an adjustable easel. The hyperspectral SWIR camera scans were saved and processed by the methodology described in the Experiment section.

The normalized data was first used with the discovery part of KemoQuant™ software to establish the MCR components. No external information about the spectra of the paints were used. With known paint materials, or information extracted from other paintings and saved in the spectral library of the KemoQuant™ software, the work could have started with those components or the iterative process could have been constrained to any or all of the known components. In this case the components were identified without any prior knowledge or information. Up to 10 components seemed relevant and substantially different. The various components either identified a single area in the painting demonstrating that it is one specific paint or one specific mixture of paints that was applied there. Other components were spread to all different parts of the painting.

Component #10 seems to show the underdrawing the best. A very detailed underdrawing is revealed. In almost all places, the drawing shows not just the outline but the shadows, the architectural details and decorations of the building, the folds of the drapery, and a small attic window at the top of the painting. The high quality of the underdrawing may reflect the use of a ready print or etching by a more experienced hand in a workshop. A few details were added to the painting layer that do not seem to show on the drawing, such as the tile pattern in the foreground, the *en grisaille* figure above the head of the column or the bead decoration over the bed on the upper right side.



Figure 3. Flemish painting and SWIR MCR Component #10.

Analysis of all the explored factors and other details will be left for further future analysis.

## Discussion

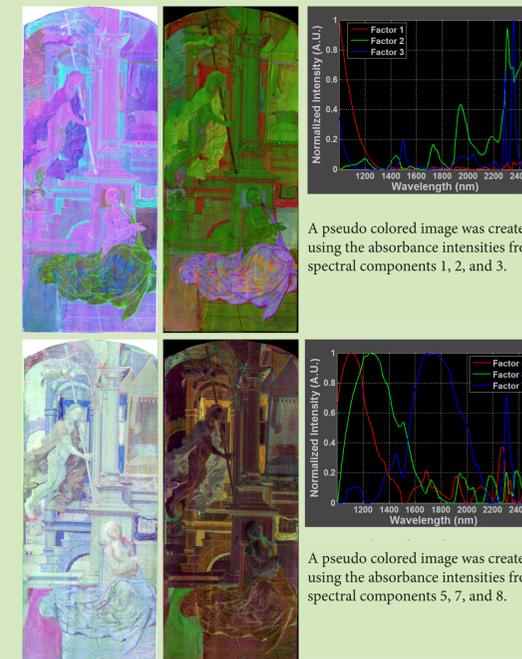


Figure 4. The various factors and the concentration images can be displayed together as three basic red-blue-green, each of which represents a separate component. The intensity of the particular component is then coded by how much of the color is in the RGB display of each pixel. For better visualization one can choose between Reflectance or Absorbance scales as shown above.

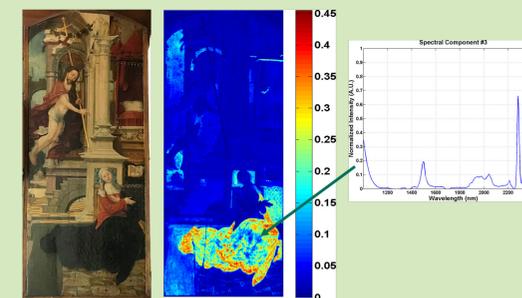


Figure 5. Spectral component of the drapery area showing larger oil spectral bands.

## References

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While the fact of the infrared transparency of most paints is well-known<sup>5,6</sup>, it is impressive how much of the under-drawing is clearly revealed using SWIR hyperspectral imaging in combination with the MCR technique. The care and detail of the drawing shows a very deliberate plan for the painting and also that the original plan was followed in detail, almost everywhere in the painting. The sky indicating a cloud and a darker area on the drawing was not implemented in the paint layer, the case behind the female figure is only decorated with rivets on the paint layer, but these differences seem very minor compared to the overall work.

A line, not part of the under-drawing, can be discovered using component #10. This feature is seen clearly vertically from where the cross and the head of Jesus intersect all the way to the bottom tiles. This line is not seen on the painting, so we can conclude that it precedes the painting and happened to the substrate before the painting was done. This detail, which may be significant to restoration work, would not be discoverable with optical analysis because the top paint layer is intact and does not reveal this line on the surface.

The largest deviation from the original plan, as witnessed in the underdrawing, is the lush details of the drapery across the female figure. The careful shading, the three-dimensional quality suggests that this large area in the foreground was part of an impressive display and was intended to be an important part of the artistic value according to the plan of the hand that did the drawing. On the painting over the drawing the drapery is very dark and the lack of detail unimpressive. It is not following the original plan, which we can speculate was intended to be colorful and uplifting. One can further speculate that in the history of the painting someone did not like the attractiveness of the cloth and ordered the planned drapery to be altered or simply painted over. The lack of the folds suggests, especially in light of the minute details in all other part of the painting, including the flying, wind-blown cape and the sleeve folds of the virgin figure, that this part was done in a haste, or even more likely by another hand. From a pious, religious point of view, the lush and perhaps colorful drapery may distract the viewer from the more important messages of the painting. Another minor adjustment in reducing the female attractiveness is noticed in the angle of the hip, which was adjusted from the drawing to a less curvy shape on the finished painting. Given the mastery of the painter and his ability to follow all minor details of the drawing, this adjustment is not likely to be due to clumsiness, inattention or lack of precision.

It is also interesting to look at the spectral component of the dark overpoint of the cloth discussed above. This is predominantly component #3, shown here with a blue-to-red, so called "Jet" coloration. This component dominates this area, with only very small and light applications elsewhere in the painting. 2300 and 2350 nm are the well-known oil spectral bands, originating from the combinations of the fundamental infrared vibrational frequencies. While oil is not a surprise component in an oil painting, it is remarkable how much larger the oil peaks are in this component relative to all other components. The spectra of most ingredients used at the time this painting was done, are known<sup>7</sup>, and further analysis may independently reveal the source and quality and shed light on the preliminary conclusions presented here. One can speculate that an excess amount of oil could originate from paint that is newer than the other parts of the painting, further corroborating the hypothesis that this less aesthetic, dark cover was applied with much less care, was left unfinished, or was applied much later.

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