Application Note – Application Note – Authentication and Detection of Forgeries in Artwork

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1.0 Authentic, Fake and Forged Art

According to the Fine Arts Experts Institute (FAEI), as much as half of the works in the roughly $60 billion art market are forgeries. Forgeries are pieces that are deliberately created in the style of an artist whose work is highly valued to deceive and perpetrate a fraud. Fakes on the other hand are misattributed works, created by artists other than one that is believed to have done so and are sometimes, though rarely, as valuable as other master works.

Although the authentication process relies mostly on the visual skills of art experts who scrutinize pieces based on style and technique, more scientific technology-based methods are growing in demand and importance as part of the verification process. Techniques range from radiocarbon dating, infrared imaging, X-rays, microscopic and chemical analysis. The costs involved can be in the tens of thousands of dollars or more. If authenticated, this process can add value by providing an objective means of certification [1,2].

Hyperspectral imaging provides a convenient and economical means to enhance and possibly obviate such costly and sometimes destructive means.

2.0 Hyperspectral Imaging

Hyperspectral imaging cameras generate 'hyper-cubes' or data-cubes of data, whereby the spectrum at each pixel in the image is collected. Subtle reflected color differences that are not observable by the human eye or even by color (RGB) cameras are immediately identifiable by comparison of spectra between pixels. A variety of spectral imaging technologies exist.

The most common type of hyperspectral imager is the push broom system whereby a line on the object plane generates a 2D pattern on an array sensor. The collection of a complete data cube (2D spatial x 1D spectral) requires mechanical scanning. While the dispersing elements can be made small and each spectrum can be collected in as short as 1ms, the mechanical motion makes these instruments somewhat bulky and prone to misalignment. Furthermore, increased spatial resolution comes at the expense of longer collection times. Push-broom grating systems were the earliest forms of the hyperspectral cameras, initially developed by NASA, mounted on satellites and airborne platforms for research purposes [5].

Band sequential or front staring imagers do not require mechanical scanning. In this technique, a tunable filter that can sequentially select spectral bands is placed in front of the sensor and generates the hyper-cube by collecting complete images at each spectral band-pass. The acquisition time does not depend on the number of pixels, but rather on the number of spectral bands being acquired. These imagers are especially attractive for applications requiring high spatial and spectral resolutions with tunable spectral ranges and a small form factor.

Often discussed along with hyperspectral imaging technology are multispectral systems, the most popular of which are based on patterned filter arrays. These are an extension of color cameras where the typical Bayer or RGB filters overlaid on the image sensor are replaced with an array of 16 or even more color filters. While no user alignment is needed, and imagers can be miniaturized, the spectral resolution is quite limited and comes at the expense of spatial resolution, making this technology inadequate for many critical sample analysis applications.

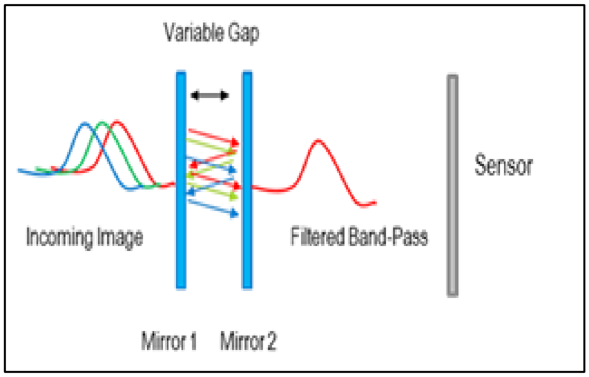

Figure 1: *Operating Principle Fabry-Perot Filter.*

Fabry-Perot interferometers (FPIs) operate by placing two mirrors parallel to each other. By controlling the reflectivity of the mirrors and their spacing, high-finesse spectral filtering can be achieved. *See figure 1.*

HinaLea Imaging developed the world's first battery-operated, hand-held staring hyperspectral camera based on FPI, *see figure 4.* This camera captures multi-megapixel imagers in 550 spectral bands in as little as two seconds. Moreover, the camera's embedded hardware enables real-time processing, so the user does not need to handle the large data sets typically generated by hyperspectral systems. Rather, the camera can identify features of interest, both in the spectral and spatial domains and classify these features in the image [6].

The technology can easily be configured into form factors and configurations suitable for laboratory bench-top investigations or production line testing. Such an implementation has not been possible for other band sequential techniques (i.e. AOTFs, liquid crystal tunable filters) due to cost, reproducibility issues, environmental, and power restrictions.

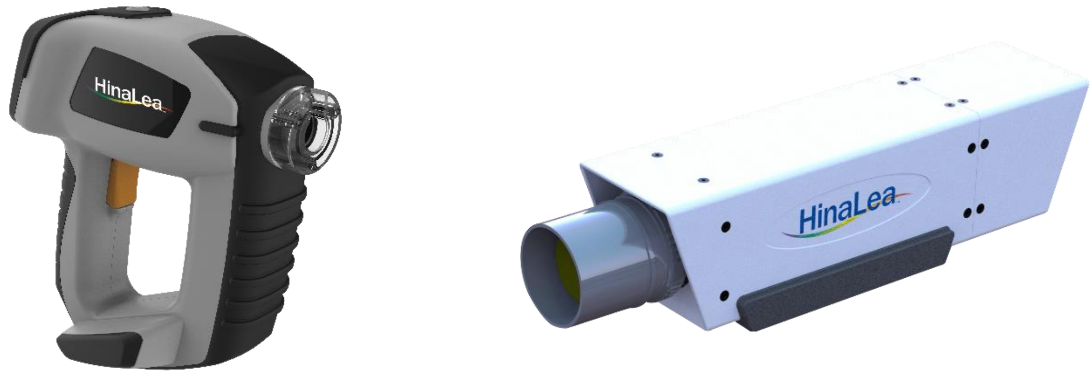

Figure 2: *HinaLea Imaging Model 4100H (left) and 4200 (right).*

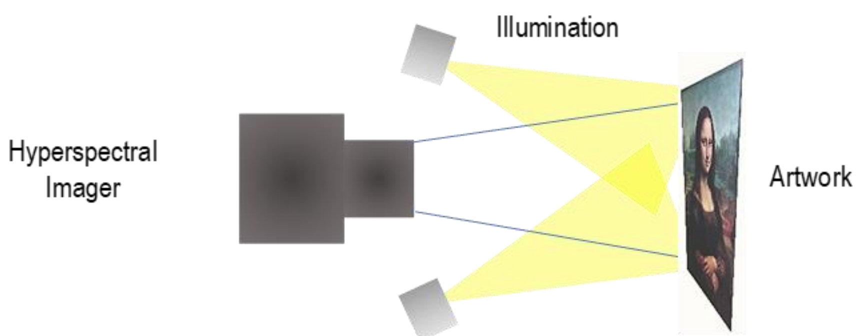

Figure 3: *Hyperspectral imaging camera configuration for artwork authentication (spectral reflectance)*

3.0 Spectral Image Processing, Unmixing and Classification

To make use of the abundance of data rendered by hyperspectral imaging, various image processing algorithms have been developed over the years. These are essentially mathematical techniques for deconvoluting the multiple spectral emission profiles or species, also referred to as end-members. As with the hardware, these techniques have their origins in satellite remote sensing research.

The most basic and common in microscopy is linear spectral unmixing. This method assumes spectra of each pixel is a linear combination (weighted average) of all end-members in the pixel and thus requires a priori knowledge (i.e. reference spectra). Various algorithms such as linear interpolation, are used to solve "n" (number of bands) equations for each pixel where the "n" is greater than the number of end-members pixel fractions.

Another popular technique, spectral angle mapping (i.e. SAM), involves a vector representation of observed and target spectra to determine closest relationships in a multi-dimensional space proportional to the number of band passes. Spectral angle mapping is widely used due to its insensitivity to brightness differences. The advent of widely accessible machine learning methods has brought a new and powerful set of tools to this endeavor. Among these include Principal Component Analysis or PCA, a dimensionality reduction technique, and K-Means Clustering, a type of unsupervised learning algorithm used to find groups in the data based on feature similarity [5].

4.0 Example of Differentiation of Visually Identical Works

Hyperspectral data cubes of three paintings, seemingly identical except for frame and dimensions, were captured (i.e. one large 'original' in frame, one large unframed 'copy' and one small unframed copy per Figure 3. The paintings were created using different paints, but significant effort was made to make them resemble one another as much as possible in terms of reproduction style and technique. Seen below is the artwork in question with two randomly selected landmarks indicated, Figure 4.

To confirm the instruments was capturing repeatable measurements of the samples, multiple measurements of the landmarks were made for each version. Scaled registration of the different size images was applied to ensure spectra from the same relative locations were identified. See below, Figure 5.

Figure 4: Image of artwork with two key landmarks indicated (eye and apple)

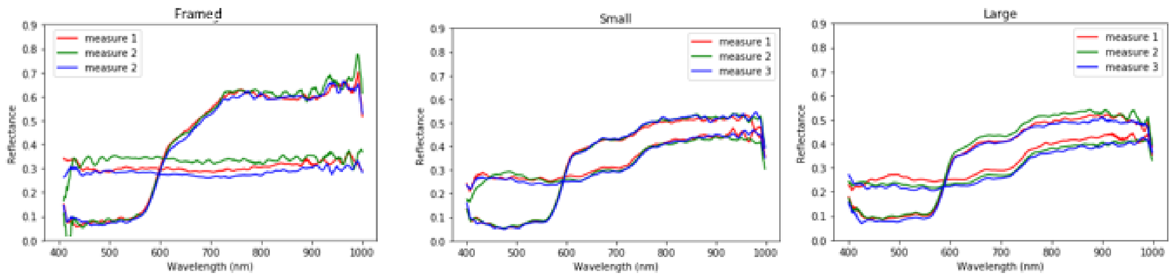

Figure 5: Repeatability measurements of landmarks of the 3 versions: framed original, small and large copy

Comparing the spectra at various landmarks on the image between the three samples there are clear and distinct differences in the spectra between the framed original and the copies. See below, Figure 6.

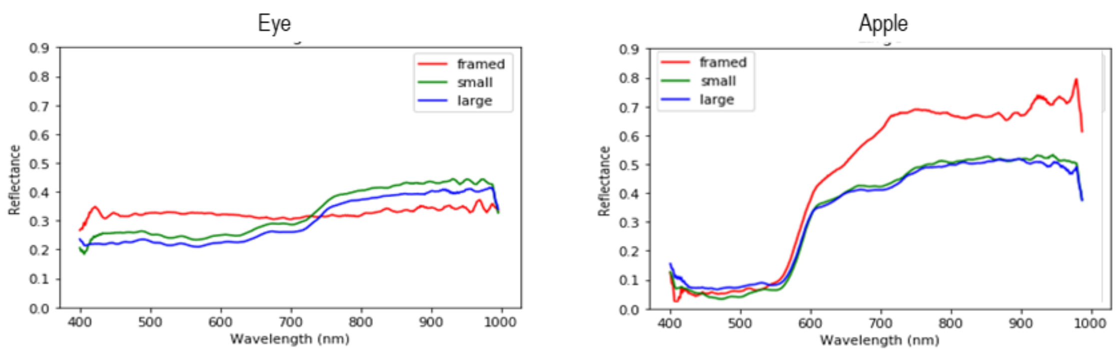

Figure 6: Comparison of spectra at eye and apple

In order to efficiently assess the authenticity of a work in its entirety, classification algorithms can be applied to the data cubes. Using the spectra from the authentic piece as the reference library for the classification we applied a spectral angle mapping algorithm to the three works. A threshold value for the spectral angle at which a pixel was considered close enough to the reference or rejected was adjusted to optimized by trial and error. Thus, the process compared spectra pixel by pixel, and if the spectral angle was larger than the threshold, it identified it as a bad pixel which meant that the piece was a counterfeit. We define the bad ratio as number of bad pixels divided by the total number of pixels. These bad pixels were indicated by a false color map of the artwork image.

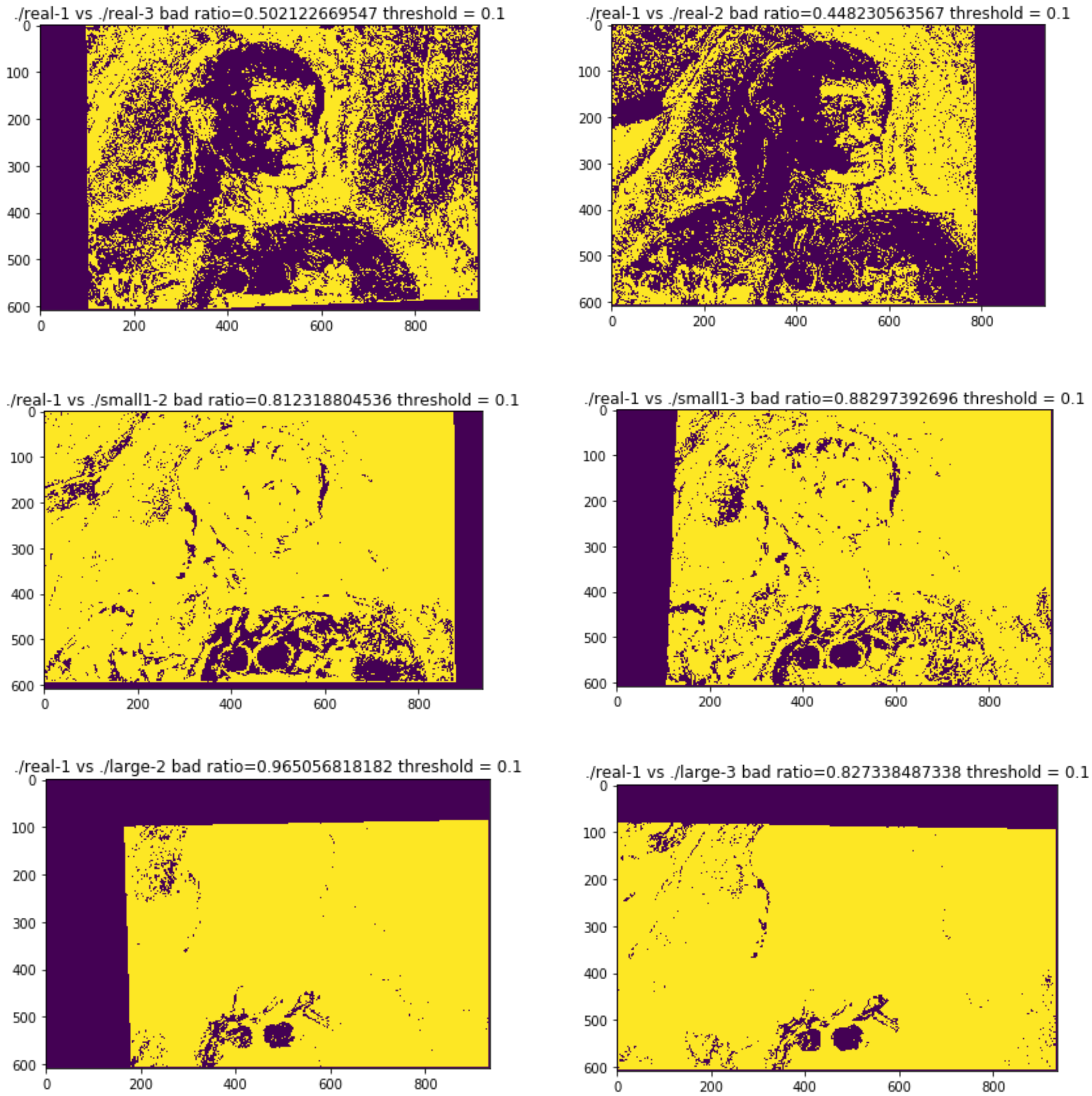

Figure 7: Multiple trials of classified images using SAM comparing the authentic to itself, to the small and large copies, respectively from top to bottom in series

It is noted that some of the area associated with the two landmarks are flagged as bad (eye) or good (apple) on most of the images, even though the spectral points sample show a difference. This can be attributed to variances that straddle the tolerance of the spectral angle threshold. However, the algorithm positively and reliably distinguishes between authentic and copy in terms of the entirety of the image. The results are intuitively interpretable. This approach thus provides a means by which non-experts can use the instrument in the process of authentication of art.

5.0 Summary

By identifying distinctions in images which are not only invisible to the eye but also to color (RGB) cameras and even multi-spectral imagers, hyperspectral imaging cameras can provide rapid assessment of the authenticity of artwork. In the examples discussed, the HinaLea Hyperspectral Imaging system was able to provide an intuitive means by which to differentiate between the original and the reproductions. This example and others serve to establish a basis for the development of a turnkey tool for use in art authentication either to augment current methods or possibly as primary tool.

The unique combination of portability and ability to dynamically change spectral range and band-pass capability of the HinaLea technology means that the same instrument can be configured for a wide variety of parameters and points of interest in the field to both optimize accuracy and reduce the time to capture image. The semiconductor manufacturing processes involved in the fabrication of the FPI means that the technology is not only miniature, yielding a lightweight and compact device, but also scalable and much more economical than competing hyperspectral technologies such as push-broom which are manually assembled. Extension farther into the infrared range of the spectrum would enable the platform to detect and analyze hidden layers of paint possibly unearthing an even more valuable treasure. Finally, the cost advantages of the technology relative to other hyperspectral imaging solutions also vastly improves access for all such potential uses.

6.0 References

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THANK YOU.

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HinaLea Imaging, a division of TruTag Technologies, Inc., is a technology solutions provider that develops complete hyperspectral imaging solutions both directly and on behalf of strategic partners to address specific problems across a variety of industries, including medical diagnostics, precision agriculture and the quality assurance of food and consumer goods. As part of its solution offering, HinaLea developed the world's first high-resolution, handheld autonomous hyperspectral camera, which was awarded the SPIE Best Camera and Imager Prism Award in 2017.