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Standards Based Authentication System and Method Using Physical Characteristics of an Object

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Abstract

The uniqueness of an object, such as an original work of art, can be demonstrated by accurately and precisely measuring "visible electromagnetic energy," VIS, found between 360 and 830 nm, reflected off the "original" specimen, the Reference, R, a specific area of the original, following a standardized measurement and transformation procedure defined by the Commission Internationale de 'Eclairage (CIE). The measured R spectra are transformed into CIE X, Y, Z values (see: CIE31) and then into CIEL*a*b* (see: CIE76) values and stored in a database protected by a block chain mechanism. To authenticate, the stored R Lab values are compared to a comparable set of Lab values, S, generated by measuring the same specific area of the specimen to be authenticated as was originally measured for R. S is compared to R via the CIE DeltaE 2000 algorithm (see CIEDeltaE00), generating a set of values, DeltaE which measure the difference between S and R for each pixel in the measured area. The mean and standard deviation of the DELTAE values over the whole measured area is found and used to create a unique *Authenticity Factor*, *AF*, the probability that the difference between any pair of corresponding cells in R and S is less than 1, the Just Noticeable Difference (JND), the CIE threshold that determines if the two specimens match. The *AF* is found from the cumulative probability function of the normal distribution of the DELTAE values of R and S. If *AF*=1, the sample perfectly matches the reference, denoting the sample is 100% authentic. *AF*<1 gives the confidence in the match between the sample and reference, ie, *AF*=.99 indicates there is a 1% chance the sample is not the same as the reference, or there is a 99% chance the sample is "authentic."

1. **Motivation:** Some years ago, during a conversation with an analog color scanner operator, the operator lamented that despite every attempt he made to adjust the $300,000 CMYK/RGB device, there were colors such as purple that he could not properly capture. Why was that, was the conversation takeaway. The answer was revealed by a close reading of, among other text books, *Wyszecki & Stiles Color Science, Concepts and Methods, Quantitative Data and Formulae, Second Edition*[1]. In fact, analog and digital color scanners and digital cameras do not measure color, they can only mix it. If you wanted to accurately and precisely specify color, a most basic form of visual perception, only measuring the light intensity coming off a specimen at particular wavelengths and then processing that data through specific algorithms would provide the answer. This insight led to our company designing instruments optimized to capture and process light using hyperspectral techniques and methods. While the military, medical researchers, astronomers and remote sensing organizations were interested in these systems, it seemed obvious that these techniques and methods should be applicable to a wider civilian market, especially in graphical imaging and reproduction. This was not the case. There were a few one-off multispectral scanners offered to the general graphics market, but none became commercially successful products. Our own hyperspectral scanners for graphical applications were not embraced by the market. RGB color was "good enough," according to market studies. We had a solution, hyperspectral imaging, that needed a problem other than remotely prospecting for minerals, sorting out stained biological samples, analyzing bomb damage, stars, forests or spotting tanks painted to blend in with forests. We needed a problem where CMYK/RGB was not "good enough."

   We therefore turned our attention to another issue we had studied for some time, Art Authentication. Here was a problem that could benefit from a standards based spectral imaging solution that relies only upon the unique physical characteristics of the art object and how those characteristics interact with light, a unique phenomenon of nature with its own immutable characteristics. The CIE offers an international standard that defined human visual perception. Hyperspectral imaging is the only scientific tool that can implement CIE standards. We therefore propose that the standard and the technology be integrated into a complete, end to end scientific analysis tool for art objects. This paper will deal only with our algorithmic implementation of a hyperspectral based imaging solution regarding how one goes about authenticating art using the described tools. The hardware solution can be inferred from the algorithms disclosed, but we are not putting forth a specific hardware solution as it is beyond the scope of this paper.

2. **Problem:** We have identified four vectors that individually or in combination determine the authenticity of an art object:

   Provenance: Titles, deeds, scholarly and media references, catalogs and other documents attesting to the object
   Markings: Stamps, seals, brush strokes, signatures, dedications, labels, inscriptions or similar tags embedded into or affixed to the object
   Expert Observation: Close and detailed visual inspection by a trained specialist, often using aides such as photography and microscopy
   Scientific Analysis: Random, ad hoc application of various scientific tools and tests

   We observe that the former three vectors, to a lesser or greater extent, rely upon human visual perception to perform analysis and the latter, scientific analysis, is invoked to bolster and substantiate the conclusions derived from the former. Based upon the direction and strength of the vectors, we conclude visual perception to be the critical determining characteristic underlying art object authentication. And therein lies the problem. Human visual perception is subjective to the individual. Our "visual perception" methodology is objective and therefore performs otherwise subjective human perceptual functions objectively. We offer an "Objective Observer."

   Humans look at things and draw their own conclusions. Humans are "Subjective Observers." We render opinions based upon subjective facts, that is, how we perceive them. Are the title documents original and not copies? We look closely. How about the gallery seal on the back of an object? Real or fake? More close visual examination. And always by an expert observer. Expert in this context means someone others have concluded is capable of rendering an "objective" opinion regarding a possible subjective set of facts. Like our "Subjective Observer," the most important mechanical tool we currently use to help us see things, photography, suffers its own "subjective observer" issue, metamerism, rendering traditional and digital photographic tools unreliable for the problem at hand. And yes, while we now can order 50 or more different scientific forms of analysis to be applied to an object, there are no agreed methods or techniques for using these tools. Each use is ad hoc and one off. Always in the mix is a subjective expert observer, viewing the object, ordering and interpreting the scientific tests, or rendering a judgment regarding the bona fides of documents attesting to the authenticity of the object.

We do not believe, going forward, the critical vectors identified will be displaced. Expert observation and judgment will continue to be applied to the object, its provenance, markings, the selection of scientific analysis and the overall authenticity of an object. The problem we want to address is how might scientific analysis and objectivity be brought more directly to bear against the known subjective nature of expert observation. In which ways might subjective human perception be made more objective and therefore more appropriate as a way to authenticate art?

3. **Approach:** To resolve the issues we raise above, we need to introduce a concept created by a scientific NGO, Commission Internationale de l'Éclairage, the CIE, also known as the International Illumination Commission. In 1931 the commission introduced the Standard, or Ideal Observer, (SO)[2], a method of measuring light that requires a source of illumination, an observer, and an object. Referred to in the literature as CIE31, both the source of illumination and the observer were mathematically defined, or standardized, by the CIE, based upon decades of research into the psychophysiological response of humans to light stimulation. These standardized factors are algorithmically combined and applied to the variable data, the light reflected off the object, yielding three coordinates that locate a specimen in an imaginary three-dimensional space, designated as the X, Y, Z Color Space. Further CIE transforms yield a second set of coordinates, designed x, y and z, that locate the measured specimen defined by the x, y and z coordinates in a 3-D, horseshoe shaped graphic. This horseshoe shaped graphic represents all colors humans might perceive and the coordinates locate a specimen within the space.

In 1976 the CIE issued further recommendations, referred to in the literature as CIE76[3], including two new three-dimensional color spaces. One, CIEL*a*b*, which featured a redefined three-dimensional map to more closely mimic the non-linear nature of human color perception, was incorporated into CIE00, a CIE recommendation issued in 2000, regarding how two CIELAB coordinate sets might be compared. Here is the nexus between subjective and objective. For the purposes of art authentication, comparing and matching two specific specimens are critical to the system being disclosed, which is based upon measuring a visual stimuli "patch" on the original work of art, the Reference, and then later comparing this measured reference with a similar "patch" belonging to the Specimen, the object to be authenticated. If the patches match, the Reference and Specimen are one in the same.

Light is a phenomenon of nature, subject to immutable rules that are understood and documented. Given a set of conditions, light always responds the same way. However, two individuals might respond differently to the same set of visual stimuli. Because of this, light becomes an ideal tool when used with CIE protocols. Two experts might disagree as to how they personally perceive light stimuli, for example if two stimuli match or not, but stimulus measured and matched via CIE protocols will always yield the same result. Because of this, if two visual stimuli match according to CIE00 standards, it is because the underlying physical characteristics of the objects match. That is, they are the same. In the case of light, the match is between wavelength and intensity. Only identical material causes a specific and identical reflection of wavelengths at particular intensities, in turn causing the measured wavelength and intensity values to decode into the same Lab values.

About now one should be asking why we need CIE protocols if all we are really doing is matching light intensities. Because we are not matching light intensities, we are matching visual perception, or how the light is perceived by humans. The complex processes utilized by the CIE are necessary to account for a quirk of human visual perception, metamerism, a psychophysiological peculiarity wherein, for example, specimens with different spectral power distributions may appear to the viewer to match under one set of conditions and not match under another. It is the reason color photography, color television, color printing and other color processes work. If one were to take a photograph and directly compare it to the original scene, one would see differences between the two. But when the image is isolated and viewed by itself, a form of metamerism fools the viewer into seeing a scene that appears to match the original exactly. Human visual senses can be tricked. Only CIE mechanisms can identify metamerism, metameric matches or metameric pairs.

Practically, to compare a single set of patches using either our process or only raw intensity values requires measuring 470 specific wavelength intensities for each of 259,200 individual specimens. If we were simply comparing wavelength intensities, without a process such as defined herein, it becomes cumbersome and tedious, but more importantly, cannot account for metamerism. Variations in light sources and sensors make normalizing and then comparing the raw measurements, probably made at different times and locations, using different systems, a continuing source of possible problems. And the end result is data in a format that people can't readily fathom. So no to simply comparing intensity values.

CIE protocols have built-in normalizing mechanisms that can account for differences in light source wavelength and output intensity. And the Ideal Observer, the variables that define our "expert," is also baked into the equations. Our "expert" always perceives similar conditions the same way, whereas two human observers may perceive similar conditions differently. Further, CIE protocols produce data, specifically Lab values, that can readily be used by humans, which means human experts can review the work of the algorithms proposed herein. The professional in this new methodology is not eliminated, but instead is tasked with confirming what the algorithm finds, not the other way around.

Here then is the new inflection point. We have a well defined and supported scientific standard that mathematically defines human visual perception via a Standard Observer. How might the

Standard Observer be applied to art authentication situations to augment or even supersede the "expert observer" in certain critical situations, for example, confirming an object unpacked after shipment is the same object that was packed for shipment in the first place.

4. **Results:** There is a straight line of inquiry one can follow to where we are now, beginning with the insights of I. Newton[4], who in the 1660s realized light rays, thought by him to be made up of extremely small corpuscles, cause sensations humans perceive as color. Some years later, in 1802, John Young[5] performed experiments demonstrating light behaved as a wave and via the Young-Helmholtz trichromatic theory postulated tiny cells within the eye receives waves of light and translates them into one of three colors, blue, green and red, that can be combined to create the entire visible spectrum of light as we see it. James Clark Maxwell approximately 60 years later, via a lantern slide presentation in London to a gobsmacked crowd of regular Friday attendees of the Royal Society, demonstrated the mechanical analog of Young's theory, the first photographically reproduced "true color" image, using an additive color process known today as RGB[6]. A burst of scientific inquiry, inspired by the 1875 *Treaty of the Metre*,[7] which established a permanent organizational structure for member governments "to act in common accord on all matters relating to units of measurement," pushed organized scientific study, including investigations into light, further faster. In 1900 the Commission Internationale de Photometrie, a precursor of the CIE, was established to study light and how humans respond to its stimulus. The study of light and its many properties had begun in earnest and the CIE, constituted in 1913 and incorporating CIP, was at the forefront of formalizing and codifying the findings, culminating in the 1931 recommendations, establishing the basics of how light should be measured and how this measured light is perceived by humans.

Light then is a phenomenon of nature following rules whose underlying characteristics were discovered following centuries of study. By understanding how to apply the rules that it follows, light can be fashioned into a precise and accurate tool that might be used for a variety of purposes. In our case, we rely upon certain of light's immutable properties, wavelength and intensity, to fashion a tool that can unfailingly authenticate objects of art.

We begin by declaring the CIE Standard Observer to be our "expert." When an opinion is required, for example when comparing two color samples, that is, the wavelength and intensity of the samples, we call upon our expert to render an opinion. Unlike a human expert who might differ with a colleague regarding how something visual might appear, or whether it matches another specimen or not, our expert always observes the same objects the same way. It is this unfailing ability to arrive at the same conclusion that is our system's strength and power.

Our authentication methodology starts with a specimen patch, an area of the "original" object randomly selected. The patch is broken down into a statistically meaningful number of individual specimens, nominally 70 μm^2. A one square inch patch, for example, may contain 129,600 specimens. The light intensity of the various wavelengths reflected off each specimen then is subject to measurement as specified by the CIE. To make the measurement, the CIE specifies the light directed onto the specimen be continuous between the wavelengths of 360 and 830 nanometers, measured in one nanometer steps. Further, the CIE specifies a series of wavelength dependent variables that describe the "Standard Observer" and the Illuminant, or light source. By combining the measured intensity of light reflected off the specimen with the published observer and light source variables via the disclosed mathematical algorithms, a set of three intermediate variables, describing the specimen as a location in an imaginary three dimensional "color space," is generated. These variables are described as X, Y and Z. Further processing decodes the variables into a secondary color space, designated x, y, and z, resulting in a horseshoe shaped graphic that depicts a map, called a chromaticity diagram, showing the relationship of all colors humans might perceive. Within this diagram can be found MacAdam Ellipses, regions of the diagram which contains all colors which are indistinguishable, to the average human eye, our Expert Observer, from the color at the center of the ellipse, established by the three chromaticity coordinates. For the purposes of this study, however, we rely upon the X, Y, Z color space variables to provide the necessary measured coordinates, and the further transforms discussed below, which account for the MacAdam Ellipse perception differences.

Mathematically, to express the X, Y and Z coordinates, we use the following algorithm, described in the literature as CIE31:

$$X = k\sum_{360}^{830} R_{(\lambda)} S_{(\lambda)} \bar{x}_{(\lambda)}$$

$$Y = k\sum_{360}^{830} R_{(\lambda)} S_{(\lambda)} \bar{y}_{(\lambda)}$$

$$Z = k\sum_{360}^{830} R_{(\lambda)} S_{(\lambda)} \bar{z}_{(\lambda)}$$

$$k = 100/\sum_{360}^{830} S_{(\lambda)} \bar{y}_{(\lambda)}$$

where the variable $R_{(\lambda)}$ is the measured spectral power distribution of the light reflected off the specimen, the variable $S_{(\lambda)}$ is the published Illuminant, or light source variables and $\bar{x}_{(\lambda)}$, $\bar{y}_{(\lambda)}$ and $\bar{z}_{(\lambda)}$ are the published color matching functions, or the Standard Observer variables. The *k* variable is a normalizing function. Each specimen in the patch is subject to the measurement and mathematical treatment described above.

Once the individual members of the specimen patch have been measured and their X, Y and Z coordinates have been established, a second algorithm is applied to the coordinates. The goal is to further manipulate the X, Y and Z values into another color space, designated CIEL*a*b*, created by the CIE in 1976 to be a more accurate representation of the non-linear human response to visual stimuli. Mathematically, we arrive at the CIELab values via the following algorithm, described in the literature as CIE76:

$$L^* = 116(Y/Y_n)^{1/3} - 16$$
$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$
$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

where:

$$X/X_n;\ Y/Y_n;\ Z/Z_n > 0.01$$

and $X_n Y_n Z_n$ are the Tristimulus values of the Illuminant selected with Y_n equal to 100 obtained by use of the same normalization method used to obtain X, Y, Z.

When one or more of the ratios X/X_n, Y/Y_n, Z/Z_n is less than 0.01 or if $Y/Y_n \leqq 0.008856$ for

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

Then

$$L^* = 903.3(Y/Y_n) \text{ where } (Y/Y_n) \leqq 0.008856$$
and
$$a^* = 500[f(X/X_n) - f(Y/Y_n)]$$
$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)]$$

Where

$f(X/X_n) = (X/X_n)^{1/3}$ when $X/X_n > 0.008856$ and
$f(X/X_n) = 7.787(X/X_n) + 16/116$ when $X/X_n \leqq 0.008856$ and
$f(Y/Y_n) = (Y/Y_n)^{1/3}$ when $Y/Y_n > 0.008856$ and
$f(Y/Y_n) = 7.787(Y/Y_n) + 16/116$ when $X/X_n \leqq 0.008856$ and
$f(Z/Z_n) = (Z/Z_n)^{1/3}$ when $Z/Z_n > 0.008856$ and
$f(Z/Z_n) = 7.787(Z/Z_n) + 16/116$ when $Z/Z_n \leqq 0.008856$.

The Lab values generated when the Reference is first examined are stored in a data base that is protected by and accessed through a block chain. To authenticate, a random patch is requested and downloaded and the next step in our authentication process can proceed. We want to compare the Lab values of the patch found on the surface of the original, the Reference, with Lab values found by measuring a similar patch found on the Specimen, or the object to be authenticated. This is accomplished using yet another CIE algorithm, designated CIE00. The goal of this comparison is to determine the JND, the Just Noticeable Difference, between any two similar specimens. The JND can be graphically represented by the MacAdam Ellipses. This difference is called the ΔE, from the German *Empfindung*, or sensation. If the JND is less than 1, the two samples are declared a match, that is, when a human viewer, in the form of our Standard Observer, compares the two samples, they appear identical. Here is the strength of the algorithm. Given the two samples, there are situations where two human viewers may differ regarding whether the samples match or not. But the CIE algorithm and its Standard Observer always yields the same result. The algorithm eliminates human variability. Because of this, comparing specimens by determining if the pairs match can be fashioned into an authentication tool. The JND comparison uses the CIEDE2000 color-difference formula. Given a pair of color values in CIELAB space L_1^*, a_1^*, b_1^* and L_2^*, a_2^*, b_2^*, we denote the CIEDE2000[8] color difference between them as follows:

$$\Delta E_{00}(L_1^*, a_1^*, b_1^*;\ L_2^*, a_2^*, b_2^*) = \Delta E_{00}^{12} = \Delta E_{00} \quad (1)$$

Given two CIELAB color value $\{L_1^*, a_1^*, b_1^*\}_{i=1}^2$ and parametric weighting factors k_L, k_C, and k_H, the process of computation of the color difference is summarized in the following equations, grouped as three main steps.

1. Calculate C_i', h_i':

$$C_{i,ab}^* = \sqrt{(a_i^*)^2 + (b_i^*)^2} \qquad i = 1, 2 \quad (2)$$

$$\bar{C}_{ab}^* = \frac{C_{1,ab}^* + C_{2,ab}^*}{2} \quad (3)$$

$$G = 0.5\left(1 - \sqrt{\frac{\bar{C}_{ab}^{*\,7}}{\bar{C}_{ab}^{*\,7} + 25^7}}\right) \quad (4)$$

$$a_i' = (1 + G)a_i^*$$
$$i = 1,2 \quad (5)$$

$$C_i' = \sqrt{(a_i')^2 + (b_i^*)^2} \qquad i = 1, 2 \quad (6)$$

$$h_i' = \begin{cases} 0 & b_i^* = a_i' = 0 \\ \tan^{-1}(b_i^*, a_i') & \text{otherwise} \end{cases} \quad i = 1, 2 \quad (7)$$

2. Calculate $\Delta L', \Delta C', \Delta H'$:

$$\Delta L' = L_2^* - L_1^* \quad (8)$$
$$\Delta C' = C_2^* - C_1^* \quad (9)$$

$$\Delta h' = \begin{cases} 0 & C_1'C_2' = 0 \\ h_2' - h_1' & C_1'C_2' \neq 0; |h_2' - h_1'| \leq 180° \\ (h_2' - h_1') - 360 & C_1'C_2' \neq 0; (h_2' - h_1') > 180° \\ (h_2' - h_1') + 360 & C_1'C_2' \neq 0; (h_2' - h_1') < -180° \end{cases} \quad (10)$$

$$\Delta H' = 2\sqrt{C_1'C_2'} \sin\left(\frac{\Delta h'}{2}\right) \quad (11)$$

3. Calculate CIEDE2000 Color-Difference ΔE_{00}:

$$\bar{L}' = (L_1^* + L_2^*)/2 \quad (12)$$
$$\bar{C}' = (C_1' + C_2')/2 \quad (13)$$

$$\bar{h}' = \begin{cases} \frac{h_1' + h_2'}{2} & |h_2' - h_1'| \leq 180°; C_1'C_2' \neq 0 \\ \frac{h_1' + h_2' + 360°}{2} & |h_2' - h_1'| > 180°; (h_1' + h_2') < 360°; C_1'C_2' \neq 0 \\ \frac{h_1' + h_2' + 360°}{2} & |h_2' - h_1'| > 180°; (h_1' + h_2') \geq 360°; C_1'C_2' \neq 0 \\ (h_1' + h_2') & C_1'C_2' = 0 \end{cases} \quad (14)$$

$$T = 1 - 0.17\cos(\bar{h}' - 30°) + 0.24\cos(2\bar{h}') + 0.32\cos(3\bar{h}' + 6°) - 0.20\cos(4\bar{h}' - 63°) \quad (15)$$

$$\Delta \emptyset = 30 \exp\left\{-\left[\frac{\bar{h}' - 275°}{25}\right]^2\right\} \quad (16)$$

$$R_c = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}} \quad (17)$$

$$S_L = 1 + \frac{0.015(\bar{L}' - 50)^2}{\sqrt{20 + (\bar{L}' - 50)^2}} \quad (18)$$

$$S_c = 1 + 0.045\bar{C}' \quad (19)$$
$$S_H = 1 + 0.015\bar{C}'T \quad (20)$$
$$R_T = -\sin(2\Delta\theta)R_c \quad (21)$$

$$\Delta E_{00}^{12} = \Delta E_{00}(L_1^*, a_1^*, b_1^*;\ L_2^*, a_2^*, b_2^*)$$

$$= \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (22)$$

Once the set of *ΔE* values is generated, another analysis is performed to confirm the veracity of the data. We describe this as the *Authenticity Factor*, or *AF*. This test examines the distribution of the *ΔE* values for each pixel in the measured area. The average and standard deviation of ΔE over the test patch are found via the following:

Average Standard Deviation

$$\overline{\Delta E} = \frac{\sum_i^n \Delta E_i}{n} \quad \sigma = \sqrt{\frac{\sum_i^n (\Delta E_i - \overline{\Delta E})^2}{n}}$$

The *Authenticity Factor* is defined as the probability that a ΔE measurement and calculation, made on any pixel in the test patch, is less than 1. This is found from the cumulative probability function of the normal distribution:

$$AF = \int_{-1}^{1} \frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot e^{-\frac{1}{2}\left(\frac{x-\overline{\Delta E}}{\sigma}\right)^2} dx$$

If the $AF = 1$, there is 100% probability that DeltaE is <1 for every pixel and the sample is a perfect visual match for the reference image. It follows if AF<1, then there is a probability that DeltaE is greater than the JND for some pixels. In this case AF gives the confidence in the match between the sample and the reference image, i.e. AF=.99, indicates there is a 1% chance the sample is not the same as the reference. In the equation above the probability density function is integrated from -1 to 1, even though ΔE >=0 to account for the possibility that the probability density function has none 0 values for ΔE. This is likely to be the case when $\overline{\Delta E}$ <<1.

5. Conclusions:

The critical vectors associated with Art Authentication rely upon human visual perception. An international scientific NGO, the CIE, has defined a special case of human visual perception, color matching. We use this matching as the nexus between a scientifically based measurement of the physical properties of an art object, the light reflected off the object, and how this light is perceived by humans, the matching, to create our method of *Art Authentication*.

The authenticity methodology described in this paper reveals a process that leverages the immutable laws of nature as they impact a natural phenomenon, light. There is no more perfect tool available. The process requires that nothing be added to or removed from the object, relying entirely upon measuring an inherent physical characteristic of the object itself, how it reflects light, rather than elements such as tags, labels, or biological markers that may be added to the object.

There have been 50 or more scientific tests and analysis of art objects used at one time or another to authenticate art, but only our method is supported by an international scientific NGO. Further, our method is most aligned with the visceral needs of humans to see it "with our own eyes." Only our scientifically based measurements, applicable to virtually any art object, can be directly observed and interpreted intuitively by humans.

Further, because of the statistical data gathered using our method, we can put a number on the confidence we have regarding the veracity of our method. While an art expert might suggest they have "high confidence" or "very high confidence" that an art object is authentic, using our *Authenticity Factor*, we can state we are, for example, 99.9% sure the object is authentic. This number is a more objective expression of confidence and should put humans more at ease with such results.

And a note regarding the physical characteristics we measure, exactly how the light reflects off an object. Objects such as paintings do change over time, subtly varying how the light reflects. Varnish layers may be added, repairs using paints or other colorants not available to the artist when the work was originally completed and the natural degrading of any pigment over time can affect the physical characteristics that our process relies upon, how the object reflects the light. The nature of the matching process we use can account for minor variations and shifts in the object. However, because of the exact and precise nature of the measurements necessary for our process, there is a side benefit to the process. Changes in the physical characteristics of the object can be mapped and used to further evaluate the condition of the object. Subtle changes in the object, not detectible via the human eye, can be spotted by the spectral analysis techniques used. Therefore, the authentication process can also be a conservation process, noting the exact condition of the object and how it changes over time.

Also, while our method utilizes the VIS portion of the electromagnetic spectrum, the basic technique of breaking down the continuum into specific wavelength dependent bands, to be analyzed and visualized, can be extended into the non-VIS spectrum. X-Ray, Ultraviolet and Infrared scans, via false color techniques, can be presented as visual representations of electromagnetic stimuli outside human perception. Such scans, when aligned with the VIS authentication observations, can offer further verification of our measurements and add significantly to our understanding of all the unique characteristics of an art object beyond that needed to authenticate the piece.

Additionally, our methodology can be applied to the provenance documents associated with and various markings found on an art object. These documents and markings can be subjected to the same analysis as the object itself, offering another layer of authentication.

When our methodology is combined with, for example, a laser scanned contour map of the surface of the object, specific pixels can be easily and exactly identified by location and this map can also be used as another example of a physical characteristic of the object. And when combined with other scientific analysis tools, for example Raman Spectroscopy, the materials used at a specific location on the object can be determined and coordinated with the spectral scan used in the initial authentication.

The process we propose is a significant technical step forward. It has three noteworthy, potentially expensive components, the systems that encode the patches, the systems that read the patches, and the systems that protect the patches. We envision the encoding systems to initially be either centrally located in large urban centers, near concentrations of high value art, or made portable and brought to, for example, a large museum where many objects can be scanned during one visit. These systems can encode Reference Patches, read Specimen Patches and encode in multiple bands. A more limited system, designed to only read but not encode patches, may be used by entities such as art handlers and smaller galleries and museums, to authenticate and confirm objects in their care. The system that contains the patches and other object-related data, the blockchain, may be operated by a third, uninterested party, tasked with protecting the patches and data from tampering or abuse.

In this paper we have suggested the process be applied to high value art, by museums, galleries, collectors and art handlers, using expensive systems that “encode,” “read” and “protect” the data. We envision encoding systems optimized for VIS, but capable of mapping the surface of the object and also encoding in the X-Ray, UV and IR bands to be commercially available. Their main job, however, may not be to encode today’s museum grade art. As the price for scans drop, a wider segment of the art community will bring their work in for analysis. Pricing will drive acceptance.

We project the commercial success of the method disclosed will not come through encoding masterworks from previous centuries. The true value of the method and its success will come from encoding the next century’s masterworks, art being made today, for the posterity ahead. Much as books today are given an ISBN number, art objects should also be so categorized. But instead of a bar code that links to a “cloud” database of facts about the book, our “barcode” brings up a “cloud” database containing patches and a detailed analysis of an art object, including a terrain model of its surface that is used to register X-ray, UV, VIS and IR scans.

We project the *Art Authentication* method suggested provides a baseline service that encourages the capture of other EM bands, which, in turn, adds value to the original authentication scan. By including end user software to efficiently view the VIS image and the various data models available and by adjusting the price for scanning contemporary art to a rate current artists and their gallerists can afford, the volume of art scanned increases, until it is universal. The art establishment won’t be fretting over fakes 100 years from now if art today is scanned as described above.

Commercially the encoding and reading systems can be procured from any number of sources that offer spectral imaging technology meeting our disclosed requirements. We estimate a complete encoding system, capable of capturing VIS and other bands, to have a six-figure price tag, with the lesser read only systems to have a five-figure price tag.

Practically we envision that a commercial entity will recognize the advantages of a next generation art encoding system and develop a hardware line that can encode in multiple bands and read patches. They might either sell the hardware and software directly to end users or create a franchise system, giving geographical territories to vendors to offer authentication and encoding services.

To successfully implement the process will require buy-in at the highest levels of the art world. Curators, benefactors, museum board members, officers, gallery directors and technical staff will need to first understand the benefits of the *AF* system and then budget accordingly. New hardware and software systems, optimized for the measurements needed, should be sourced and put online. Art experts will need training to learn how to work with the new systems. Museums and collectors from around the world will need to bring their art in for scanning and authentication. But most critically, art teachers and students, contemporary artists and gallerists, must be educated to understand the benefits of multi-band imaging and demand their work to be scanned, not photographed.

6. References:

[1] Gunter Wyszecki, W. S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd Edition, Chapter 3, Colorimetry. ISBN: 978-0-471-39918-6.

[2] *CIE (1932). Commission internationale de l'Eclairage proceedings, 1931. Cambridge: Cambridge University Press.*

[3] CIE 15:2004, Technical Report: Colorimetry, 8.2.1.1, 3rd edition.

[4] I. Newton, *New Theory of Light and Colours*, Philosophical Transactions of the Royal Society, February 1672

[5] John Young, *On the Theory of Light and Colors*, Bakerian Lecture, The Royal Society, 31 December 1802

[6] Maxwell, J.C.; Niven, W.D. (Eds.) On the Theory of Three Primary Colours. In *The Scientific Papers of James Clerk Maxwell*; Cambridge Library Collection—Physical Sciences; Cambridge University Press: Cambridge, UK, 2011; Volume 1, pp. 445–450

[7] *"Treaty of the Metre". Encyclopædia Britannica. 2013.*

[8] Gaurav Sharma, Wencheng Wu, Edul N. Dalal, *The CIEDE2000 Color-Difference Formula: Implementation Notes, Supplementary Test Data, and Mathematical Observations*, COLOR research and application, Volume 30, Number 1, 1 February 2005.

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The author, CEO of Spectral Masters Digital Imaging, Inc., develops hyperspectral imaging systems for graphical, medical and military applications and has been granted four patents in the area. Based upon insights gained working with CIE protocols, the concept of a unique art authentication method using only the physical characteristics of an art object, the CIE protocols, statistical modeling and block chains was created.