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# Improved acquisition of underdrawings in oil-paintings using IR-reflectography

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SIMG-503

Senior Research

# Improved Acquisition of Underdrawings in Oil-Paintings Using IR-Reflectography

Final Report

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# Improved Acquisition Technique of Underdrawings in Oil-Paintings Using IR-Reflectography

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**Abstract**

Forms of infrared analysis have been widely used to evaluate underdrawings in works of art. Although infrared analysis offers an easy yet nondestructive means of removing the overlying paint from the underdrawings without any damage to the painting, rarely has an underdrawing been fully exposed by any method of infrared analysis. This limited success is due to several factors, including paint layers or other artifacts that absorb and scatter most of the infrared radiation and underdrawings that do not reflect infrared radiation. This thesis proposes additional steps be taken in the infrared reflectography method to help solve one of these problems. It is possible to expose a larger portion of the underdrawing by using approximations of the Kubelka-Munk theory to evaluate the infrared and visible radiation reflected by a painting.

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This report is accepted in partial fulfillment of the requirements of the course SIMG-503 Senior Research.

Title: Improved Acquisition Technique of Underdrawings in Oil-Paintings Using IR-Reflectography
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# Improved Acquisition Technique of Underdrawings in Oil-Paintings Using IR-Reflectography

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**Acknowledgement**

There are many people who have helped guide me along the way while performing this research. I would like to take this opportunity to thank my parents for giving me advice and support during my years at RIT. I would also like to thank my fiancée, Kristen, who has had to endure my moods while I was frustrated and confused when the research didn't go quite as expected. Most of all, I would like to thank Dr. Jon Arney, who through his guidance, wisdom, patience, and good nature, I have learned more from than any course I have ever taken. Thank you all.

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# Improved Acquisition Technique of Underdrawings in Oil-Paintings Using IR-Reflectography

Chad Weiner

## Introduction

Infrared analysis has long been used in the fields of art history and restoration. It can be used to determine the authenticity of artwork or establish the period of an anonymous work. However, the most commonly used application of infrared radiation in regards to painting analysis is the unmasking of underdrawings. Infrared analysis provides an easy yet nondestructive means of removing the overlying paint from the underdrawings of many pieces of art. However, most documented processes have only made use of infrared imaging, while ignoring the possibilities for a clearer, higher contrast image of an underdrawing by comparing images in the visible and infrared regions. Prior infrared analysis techniques also have been unable to successfully expose portions of underdrawings that are hidden by mediums that reflect infrared radiation.

## Background

### Underdrawings

Underdrawings can be found in many works of art from any time period. An underdrawing is a preparatory drawing for a painting sketched directly on a ground. Underdrawings are typically sketched using charcoal, but artists have been known to also use chalk, pencil, or paint and brush and other media. These underdrawings are later covered with the artist's medium. Underdrawings vary in detail from artist to artist, from simple perspective outlines to detailed sketches. Therefore, an underdrawing can provide much insight into the creative process of an individual artist [1].

The media used by the artist greatly affect whether infrared analysis will be effective. The materials used for the underdrawings must be able to reflect radiation in the infrared region, such as charcoal or graphite. Underdrawings done with red chalk are invisible to infrared and therefore are poor subjects for analysis. White chalk sketched on a dark ground has also been found to be difficult to analyze. For infrared analysis to effectively expose an underdrawing it is also necessary for infrared radiation must be able to pass through the paint layer of a piece of art. Using infrared analysis to image an underdrawing also becomes impossible if the pigments have large amounts of energy absorbing carbon. As the thickness of the overlaying paint layer increases, the ability to successfully image the underdrawing is diminished [2].

### Kubelka-Munk Theory

The optical theory of Kubelka-Munk is needed to understand the interaction of the paints and infrared radiation. Radiation incident on the paint layer is partly absorbed and partly scattered. Scattering of the initial flux causes diffusion of the light. Internal reflectance exists when the diffuse flux reflected from the canvas is then reflected by the under-side of the paint layer [3]. Using Kubelka's work, the reflectance of a uniform paint layer (R) of a certain thickness (X) can be found using the formula:

$$R = \frac{1 - R_G \cdot \left[a - b \cdot \coth(b \cdot S \cdot X)\right]}{a - R_G + b \cdot \coth(b \cdot S \cdot X)},$$

where a and b are defined by the equations:

$$a = \frac{S + K}{S},$$

$$b = \sqrt{a^2 - 1},$$

where $R_G$
is the background of reflectance, S is the scattering coefficient of the paint layer and K is the absorption coefficient [3]. Therefore the successfulness of exposing the underdrawing is most affected by the scattering power of the paint layer and the thickness of the paint layer. The ability to extract the underdrawing is also affected by the contrast of both layers. As the wavelength of the radiation increases, the scattering by the particles is reduced. Therefore, at a longer wavelength, the radiation is able to pass through the layers of paint to be reflected or absorbed by the underdrawing. Therefore, infrared radiation is capable of passing through the paint layer while visible radiation is reflected by it. The limitations of wavelength exist in the thermal IR, at about 5.0 mm [4].

There are some limitations that exist in the Kubelka-Munk theory. Since the theory assumes that Lambert's law is true, the specular reflectance from the upper side of the film boundary is not considered. This in turn means that the theory would be applicable only if the pigments are contained in a medium with the same index of refraction as the surrounding medium [5]. However, since it is only necessary to find an approximation of the relationship of the paint layer thickness to the radiation wavelength, Lambert's law is unimportant [6]. Another assumption is that there is uniformity of the scattering and absorption coefficients throughout the paint layer, which rarely occurs in older paintings. The absorption coefficient and scattering coefficient are both related to the pigment/medium ratio, or pigment volume concentration. For many paintings, pigments were hand ground and were therefore not uniform in size [5]. Again, however, various influences such as the refractive indices of the media and the need for uniformity of particle size can be disregarded because the relationship between thickness and wavelength must only be approximated [6]. Another limitation of the Kubelka-Munk theory is that its parameters are dependent on wavelength [5].

## Infrared Photography

Although infrared photography was the first form of infrared analysis to be applied to paintings, it has now been replaced by infrared reflectography in most instances. It was discovered in the late 19th century that black and white film normally sensitive to only ultraviolet and visible light could be extended to react to infrared light by adding dyes to the silver halide crystals. This obviously lengthens the silver halide crystals, which in turn allows the molecules to be sensitive to higher wavelengths. Films that originally were sensitive to a wavelength less than 0.5 m could then respond to wavelengths up to 1.1 m [3]. Unfortunately, this also lowers the upper limit of the film sensitivity, and therefore while the film still remains sensitive to the red and flesh-tone pigments it can no longer penetrate the blues and greens [7]. In any other regard the procedure is similar to the normal photographic process.

Infrared false color film introduces a different method. Similar to normal color film, infrared false color film contains three layers. With normal color film, one layer is sensitive to the visible blue region, while another is sensitive to the visible green and a third is sensitive to the visible red. To allow for detection in the infrared region, the sensitivity of the film must again be shifted. Therefore, while one layer is sensitive to the green band and another is sensitive to the red, the third is sensitive to the near infrared region. A filter is needed to remove blue radiation from the system, as all three layers are sensitive to it [8].

Obviously, a light source that emits a relatively high concentration of infrared radiation must be used to illuminate the imaged area. Tungsten filament lamps, quartz lamps or an average glass bulb can be used to illuminate the imaged area for either method. Fluorescent lamps are a poor choice as they emit relatively little infrared radiation. The glass covering of the lamp or bulb should always be clear because the phosphorus coating will decrease the amount of infrared radiation [2].

There are several limitations of infrared photography. The largest obstacle is that often the entire underdrawing is not visible using infrared photography. While the both infrared photography techniques do well in removing certain colors, they are unable to penetrate others. Paintings in reds, whites and browns provide the best results, while blue and some green parts of paintings can not be penetrated using this technique. Therefore, while the underdrawing is usually visible from under the lighter-colored areas, blue and some green areas of the paintings will appear entirely black.

## Infrared Reflectography

Asperen de Boer first developed infrared reflectography in the 1960's using a lead-sulfide detector, which had a peak response of 2 microns. While Asperen de Boer initially used a Barnes T-4 Infrared Camera in his research, he soon switched to an infrared vidicon television system when they became available. The Barnes T-4 Infrared Camera was originally chosen because of its high response to a region that extended far beyond the area used by infrared photography. Although satisfactory results were achieved, the Barnes camera also offered several disadvantages, including difficult mirror optics design, heavy and cumbersome instruments, difficulties in analyzing large paintings, and a high cost. The infrared vidicon television system helped to solve these problems [5].

Infrared reflectography using a vidicon tube system soon became the preferred method of infrared analysis. Vidicon systems typically have a sensitivity that reaches about 2.0 mm. It was determined that the 1.5 - 2.0 mm region best reveals underdrawings done in chalk, charcoal, metals and inks [4]. In a vidicon tube system, a television camera is fitted with a vidicon tube, which is sensitive to infrared radiation. This is directly connected to a Digital Image Processing system and the resultant image is displayed on a monitor. The same lamps used for infrared photography can be used to illuminate the imaged area. Filters can be placed in front of the imaged area to remove the visible radiation in order to reduce the resolution of the vidicon tube system [9]. Use of a filter becomes necessary as the thickness of a paint layer increases [3]. However, problems existed with the infrared vidicon television system. The vidicon tube is highly sensitive and can easily be damaged by over-exposure. Also, as the tube causes thermal noise as it heats up, and the system can only be operated for periods of about an hour at a time [3].

An infrared reflectography system using a silicon CCD camera was first developed in the 1990's and is still currently used. Solid state CCD systems can range in sensitivity (typically anywhere in the range of 0.6 to 5.7 mm). A solid state CCD system are better than the vidicon tube system in terms of geometric distortion, signal stability, linearity and MTF. All of these characteristics improve the overall image quality [10]. Solid state CCD systems are also superior to vidicon tube systems in regards to sensitivity. This is most likely due to a CCD's high light sensitivity, low noise and high contrast that exists at any resolution [11]. Because a video system is restricted to 640x480 pixels, sampling areas of the painting and piecing them together into a "mosaic" will obtain the best results. Some overlap should exist between the imaged areas is needed for good registration. Twenty percent has proved to be a sufficient amount of overlap to recognize similar features while still keeping the number of images to a minimum [10]. Unfortunately, this need for a "mosaic of images" created difficulties. Because edges can appear within the result, there is a need for near-uniform illumination of the image space.

To eliminate the need for a "mosaic," D. Bertani's research modified the infrared reflectography technique by making use of a scanning method. The infrared detector used in Bertani's procedure was a simple optical head placed at the center of the image. A pinhole with a diameter of 0.4 mm was then placed in front of the detector so an object area of 0.2 mm could be sampled when the optical magnification was 2:1. A translation system was then used to move the optical head and a small illuminator along the X-Y plane. A personal computer made use of a 12-bit analog-to-digital converter to sample and digitize the output signal of the detector. An ATVISTA image-processing board then displayed the final result [12]. The use of a scanner removed the need for a "mosaic" and the result was a smoother image that requires less manipulation. It was also found that the image exhibited greater definition and legibility by using the infrared scanning method [12].

Infrared reflectography is able to alleviate some of the problems found in infrared photography. The greatest advantage is the increased sensitivity of infrared reflectography systems over infrared photography systems. Therefore, while an underdrawing will still remain hidden under most blue areas of a painting, the underdrawing is now visible in all green areas of the painting. Other advantages of infrared reflectography over infrared photography include speed and the ease of use. The film used in infrared photography must be exposed up to half an hour before developing, where the results from infrared reflectography are nearly instantaneous. Another drawback to infrared photography is photographs and film will deteriorate with age. However, the final result in infrared reflectography is digital, and as a result images captured using this method will not degrade over time. Also, details can be manipulated and enhanced using infrared reflectography. Overall, an infrared reflectography system is less expensive than one for infrared photography [3].

Despite improvements, there are still limitations to the infrared reflectography method. The most difficult of these problems is that this method is still unable to penetrate blue areas of the painting. A related problem is that this method is unable to expose parts of an underdrawing covered by a medium that absorbs and reflects infrared radiation. The use of filters requires the illumination level of the imaged area to be increased. It is necessary for the X-Y translation of the object on a plane that is perpendicular to the camera. Images can still appear grayish and may therefore have poor contrast. Optical and geometrical distortions can be caused by the camera and must therefore be taken into account by the software when analyzing the data. However, the interpolation utilized by the software to correct these problems can also create errors and artifacts in the resulting image [12].

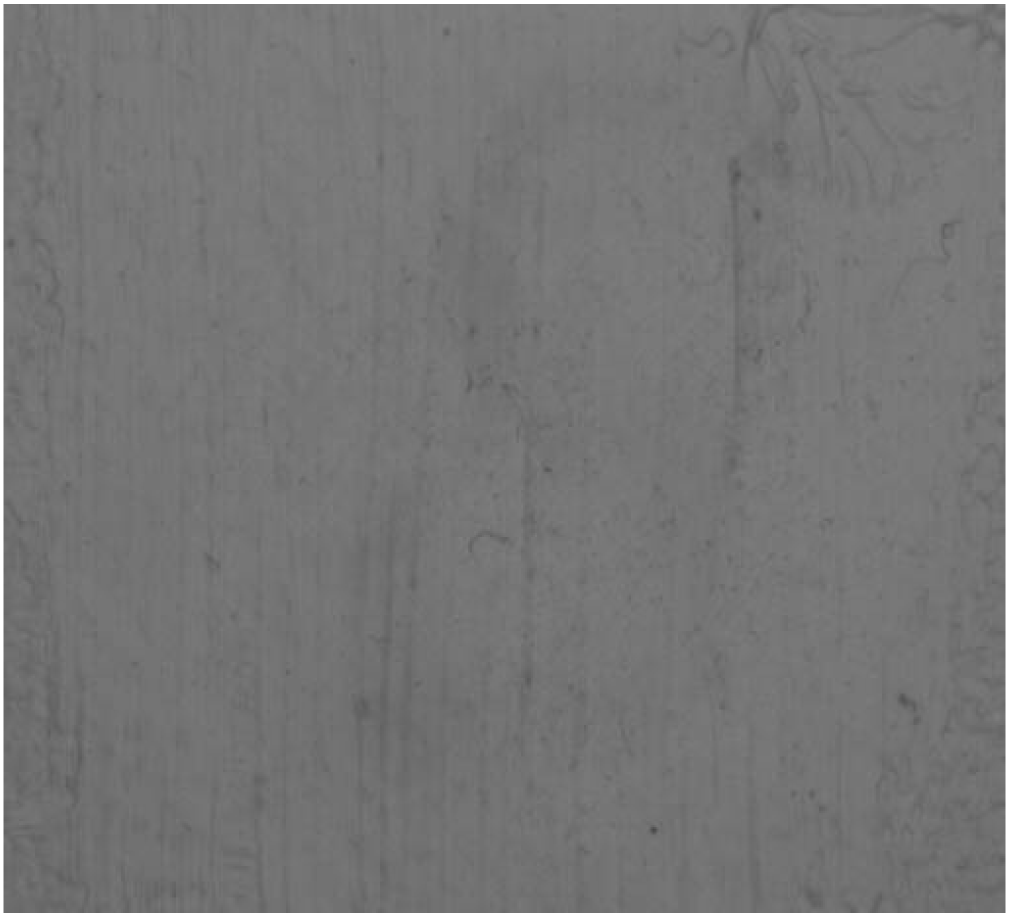

*Image B.1: Visible Image of a Sample*

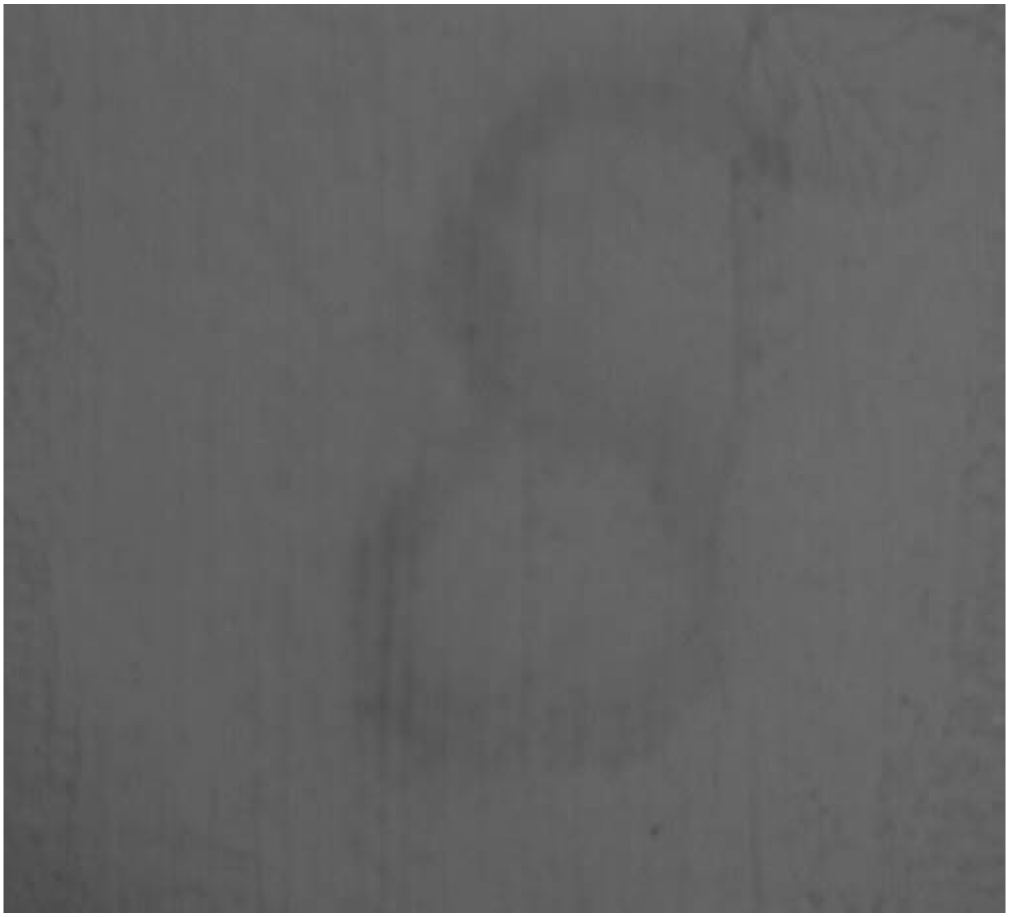

*Image B.2: Infrared Image of a Sample*

## Digital Image Processing in Infrared Analysis

Although most infrared analysis research dealt with only the capture of an infrared image, there have been a few studies in which Digital Image Processing techniques have been used to analyze the data. J. Coddington made use of several digital image processing techniques, including contrast enhancement and histogram modifications, to obtain a larger amount of useful information from digitized infrared images. For this study, Coddington used an infrared reflectography - vidicon system to capture infrared images. Coddington was then able to use the software package, Mosart, and software included with the Matrox 1024b PIP digitizing board to mosaic and to accomplish several manipulations to enhance the image. It was found that the fragments of underdrawings became more visible after expanding the images' histograms [13].

*Image B.3: Enhanced Contrast of Infrared Image (Image B.2)*

The technique that is proposed by this research draws from many of these previous studies. For this research, the infrared reflectography - CCD camera method was used. The CCD camera captured images of the underdrawing in both the visible and infrared regions. In order to uncover the underdrawing, approximations of the Kubelka-Munk theory were applied to compare the differences between the two images. It was expected that this process would be able to uncover an underdrawing even when behind a medium that is able to reflect infrared radiation. By doing so, this method was expected to offer the best of the previously described procedures; it allows for the entire underdrawing to be visible and will offer higher contrast by using differences between images captured in the visible and infrared regions rather than relying on solely an infrared image.

# Theory

## Kubelka-Munk Theory

An understanding of the optical theory of Kubelka-Munk is necessary to determine the interaction of paint with light, or more specifically for this case the differences between the interaction of paint with visible radiation versus the interaction of paint with infrared radiation. The light flux incident on a paint layer is partly absorbed and partly scattered. The flux that is neither absorbed nor scattered by the surface of the paint is able to penetrate the paint layer. Diffusion of the light is created by the initial scattering and the re-scattering of the penetrating flux [5]. Internal reflectance exists when the diffuse flux is reflected by the ground and then by the under-side of the paint layer [3].

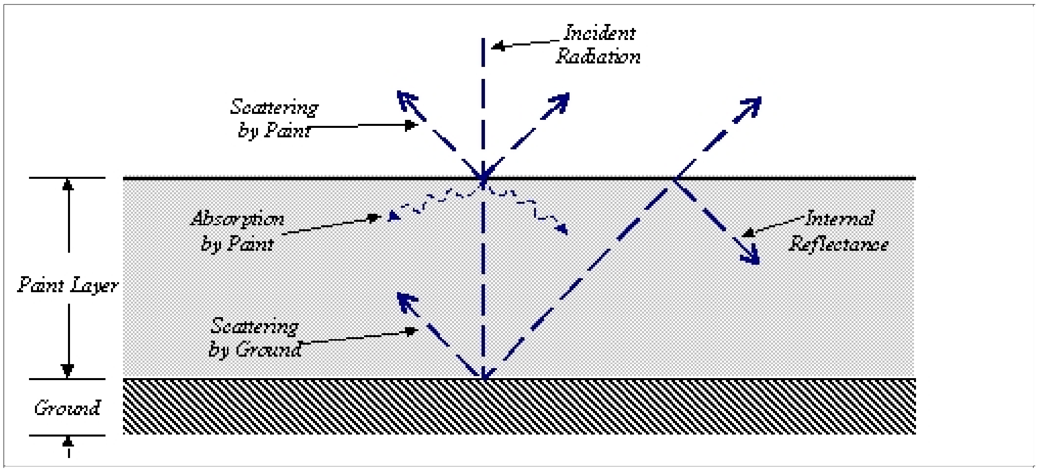


*Image T.1: Interaction of Light with Paint Layer and Ground*

The exact fractions of the light that are scattered and absorbed are defined by the coefficients S and K, respectively. Both of these coefficients are directly dependent on the thickness of the paint layer, which is defined by the variable x. The absorption coefficient and the scattering coefficient also vary with regards to the pigments used in a paint. The difference between the absorption coefficient and the scattering coefficient can be found by the equation:

$$\frac{K}{S} = \frac{(1 - R_o)^2}{2 \cdot R_o} .$$

If a paint layer has a black background, it can be considered to be perfectly absorbing. Therefore, the reflectance of this layer of paint with a finite thickness is found to be a function of the scattering coefficient:

$$S \cdot X = b^{-1} \cdot \coth\left(\frac{1 - a \cdot R_o}{b \cdot R_o}\right),$$

where a and b are defined by the equations:

$$a = \frac{1}{2} \cdot \left(R_o^{-1} + R_o\right),$$

$$b = \frac{1}{2} \cdot \left(R_o^{-1} - R_o\right)$$ [14].

Unfortunately, this ideally simplified equation does not usually exist for most situations. However, by using Kubelka's work varying absorption can be considered when determining the reflectance of a uniform paint layer of a certain thickness through the use of the following formula:

$$R = \frac{1 - R_G \cdot [a - b \cdot \coth(b \cdot S \cdot X)]}{a - R_G + b \cdot \coth(b \cdot S \cdot X)},$$

where a and b are defined by the equations:

$$a = \frac{1}{2}\cdot\left(R_o^{-1} + R_o\right),$$

$$b = \frac{1}{2}\cdot\left(R_o^{-1} - R_o\right),$$

where $R_G$ is the ground reflectance, S is the scattering coefficient of the paint layer and K is the absorption coefficient [3]. When an underdrawing exists, the background of a paint layer will have two distinctly different reflectances, $R_B$ (background reflectance of the underdrawing) and $R_W$ (background reflectance of the ground). As the paint layer reflectance is dependent on the background reflectance, the paint layer will also exhibit two distinctly different reflectances. The contrast-ratio between these two paint layer reflectances is therefore found to be:

$$k = \frac{R_{pB}}{R_{pG}},$$

where $R_{pB}$ is the paint layer reflectance of the underdrawing and $R_{pG}$ is the paint layer reflectance of the ground. To obtain a certain contrast-ratio the layer thickness must equal the value $X_D$. The contrast-ratio can then be found using the equation:

$$k = \frac{R_{pB}}{R_{pG}} = \frac{1 - R_B\cdot\left[a - b\cdot\coth(b\cdot S\cdot X_D)\right]}{1 - R_G\cdot\left[a - b\cdot\coth(b\cdot S\cdot X_D)\right]}\cdot\frac{a - R_G + b\cdot\coth\left(b\cdot S\cdot X_D\right)}{a - R_B + b\cdot\coth(b\cdot S\cdot X_D)},$$

The value $X_D$ is known as the hiding thickness. Therefore, an imaging system is able to differentiate between the background reflectance of the underdrawing and the background reflectance of the ground when the paint layer thickness is less than the hiding thickness [5]. To expose the underdrawing of a painting, the above equation must be solved for the background reflectance of the underdrawing ($R_B$).

## Approximations of Kubelka-Munk Theory

Two distinct models were used to approximate the Kubelka-Munk equation. While the exact fractions of the light that are scattered or absorbed are dependent on the thickness of the paint layer, the paint layer thickness can be disregarded because it is infinitesimally small for this case. In the equations, $P_{VIS}(x, y)$ defines the visible image and $P_{IR}(x, y)$ defines the infrared image, while the resulting underdrawing image is defined as $P_{UD}(x, y)$. The variables S and K correspond to the scattering and absorption coefficients. Both equations used a scaling and shifting factor ($X_1$ and $X_2$, respectively). Therefore, an increase in the value of $X_1$ would create an increase in the contrast of the image, while an increase in the value of $X_2$ would cause an increase in the total brightness of the image. These equations are:

(1) $$P_{UD}(x,y) = X_1\cdot\left[\overline{\left(P_{VIS}(x,y) + S\right)^K}\cdot\frac{P_{IR}(x,y)}{\left(P_{VIS}(x,y) + S\right)^K}\right] + X_2,$$

(2) $$P_{UD}(x,y) = X_1\cdot\left|\overline{\left(P_{VIS}(x,y)\cdot S\right)^K} + \left[P_{IR}(x,y) - \left(P_{VIS}(x,y)\cdot S\right)^K\right]\right| + X_2.$$

# Methods

## Sample Preparation

Each sample was created using a swatch of canvas approximately 2" by 2" square. Each swatch was prepped by sketching a design on the surface using an artist's charcoal pencil. A thin coating of flake-white oil-based paint was then applied to conceal this sketch. Flake-white oil-based paint was chosen for this research because its index of refraction is approximately equal to the index of refraction for linseed oil. This can be partly attributed to the lead found in flake-white. Had it been necessary to use linseed oil to thin the paint, the choice of flake-white paint would have cut out a needless calculation. It has also been determined that lead white paint is the most common admixture found in oil paintings [5]. After the paint dried, a second sketch was applied to the surface. The second sketch always had a different orientation than the first. This was necessary to help determine

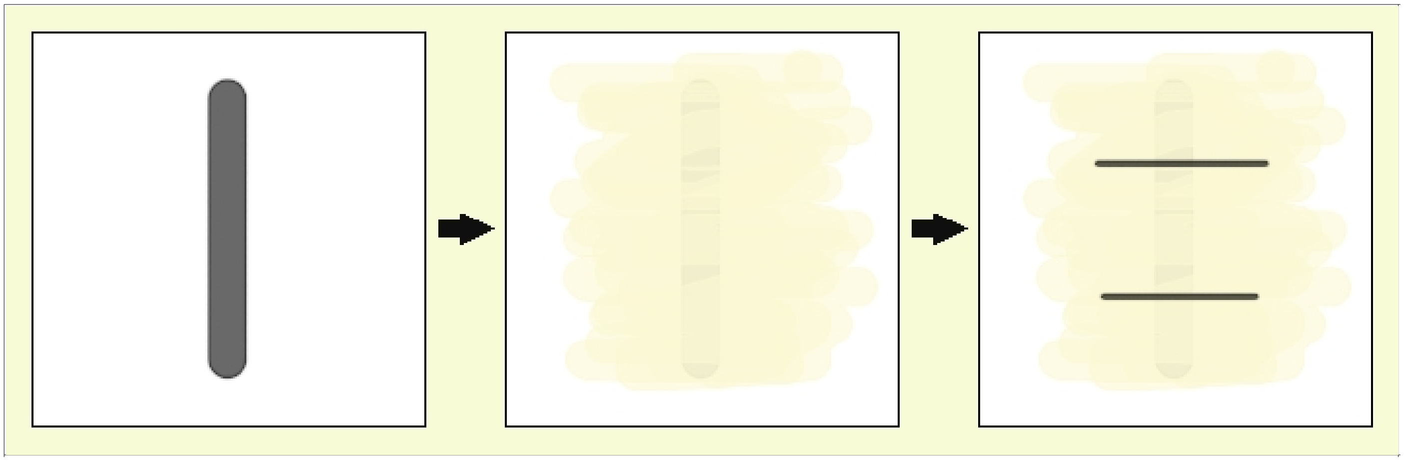

*Image M.1: Preparation of Samples*

For these samples, the original sketch simulated the underdrawing while the oil-based paint and second sketch would simulate the overlying paint layer of a piece of art. The second sketch is of particular interest as previous methods of infrared analysis were unable to remove it.

## Image Capture

For this research, a Cohu CCD camera was connected to a 386 clone PC with a standard black and white video monitor. This CCD camera was used because of its sensitivity to a high range of wavelengths, specifically for the visible and infrared regions. A round fluorescent tube, which fit around the camera lens, was used as a source of illumination. Although this lamp wasn't necessary to produce solid results, it helped to create equal illumination across the image. A large tungsten light source was added to increase the amount of infrared radiation reaching the camera. The software program IMLAB was used to capture and save the image. This setup was used to obtain two images of each sample: one in the visible and the other in the infrared. Samples were first imaged in the visible region. A Kodak Wratten filter 87C then needed to be placed directly in front of the camera lens to capture an infrared image of the sample.

## Digital Image Processing

The images were analyzed and compared using both a Visual Basic program and MathCAD 7.0. For both, approximations of the Kubelka-Munk theory were used to simulate the scattering and absorption of light caused by the oil-based paint layer. These approximations, as noted in the Theory section, are:

$$P_{UD}(x,y) = X_1 \cdot \left[ \sqrt{(P_{VIS}(x,y)+S)^K} \cdot \frac{P_{IR}(x,y)}{(P_{VIS}(x,y)+S)^K} \right] + X_2 \quad (1)$$

$$P_{UD}(x,y) = X_1 \cdot \left[ \sqrt{(P_{VIS}(x,y) \cdot S)^K} + \left[ P_{IR}(x,y) - (P_{VIS}(x,y) \cdot S)^K \right] \right] + X_2 \quad (2)$$

For each set of infrared and visible images, the values of S and K were adjusted until the underdrawing was exposed as much as possible. The variable $X_1$ was used to adjust the contrast of the image as needed while the variable $X_2$ was used to increase the overall brightness of the resulting image.

# Results

It was determined through the analysis of five samples that both approximations appeared to work equally well to expose the underdrawing from the layers above. Further, it was found that no single value for the scattering coefficient worked equally well for all the samples tested. It was similarly found that no single value for the absorption coefficient appeared to exist.

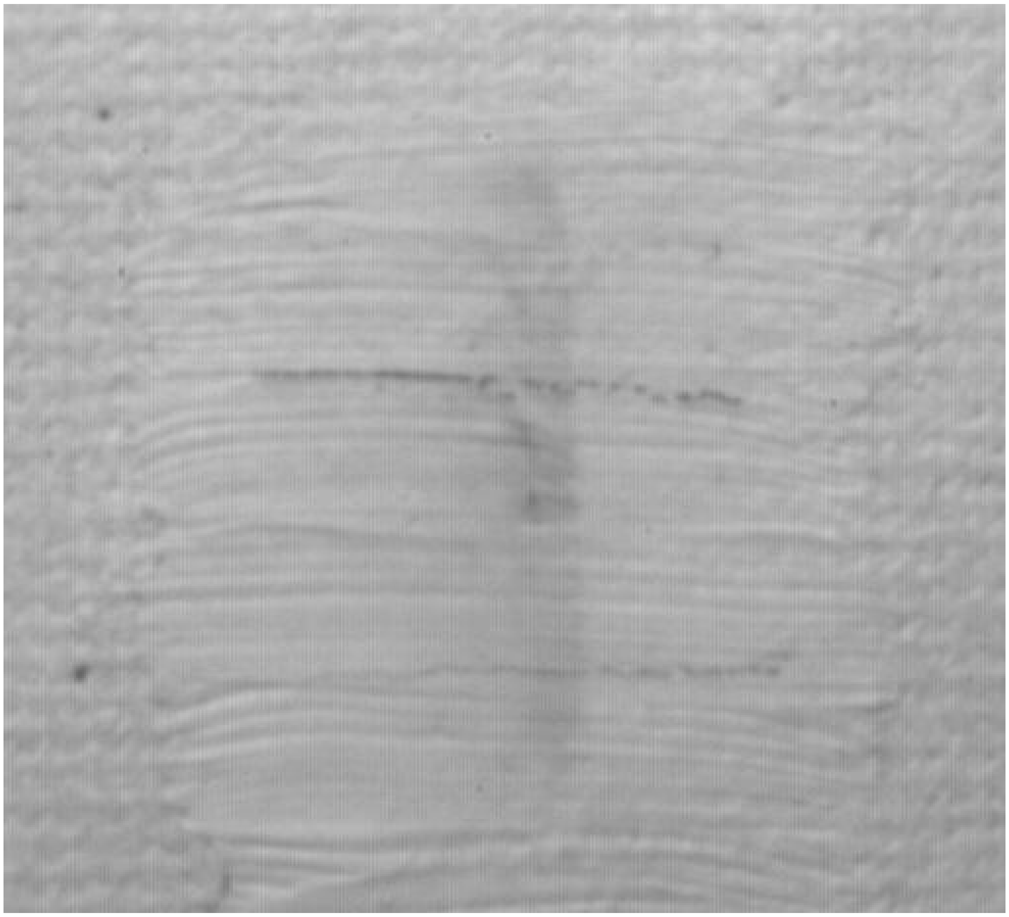

*Image R.1: Visible Image of a Sample*

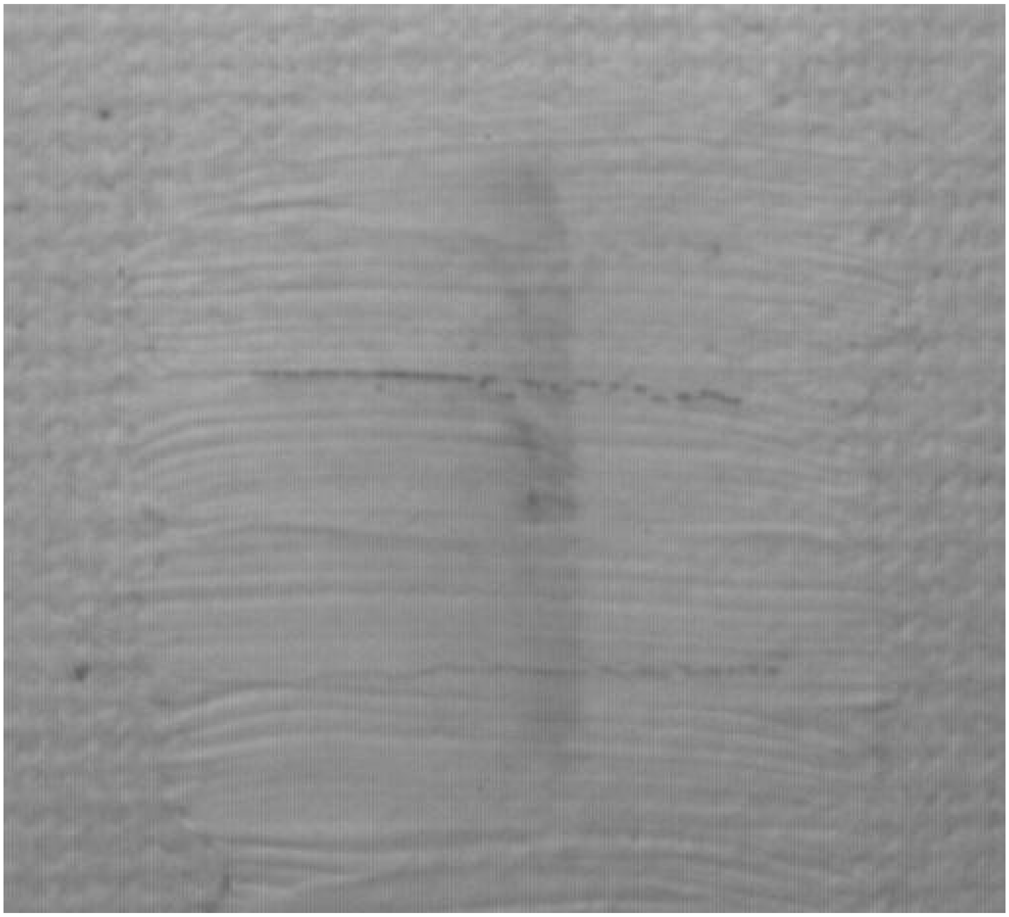

*Image R.2: Infrared Image of a Sample*

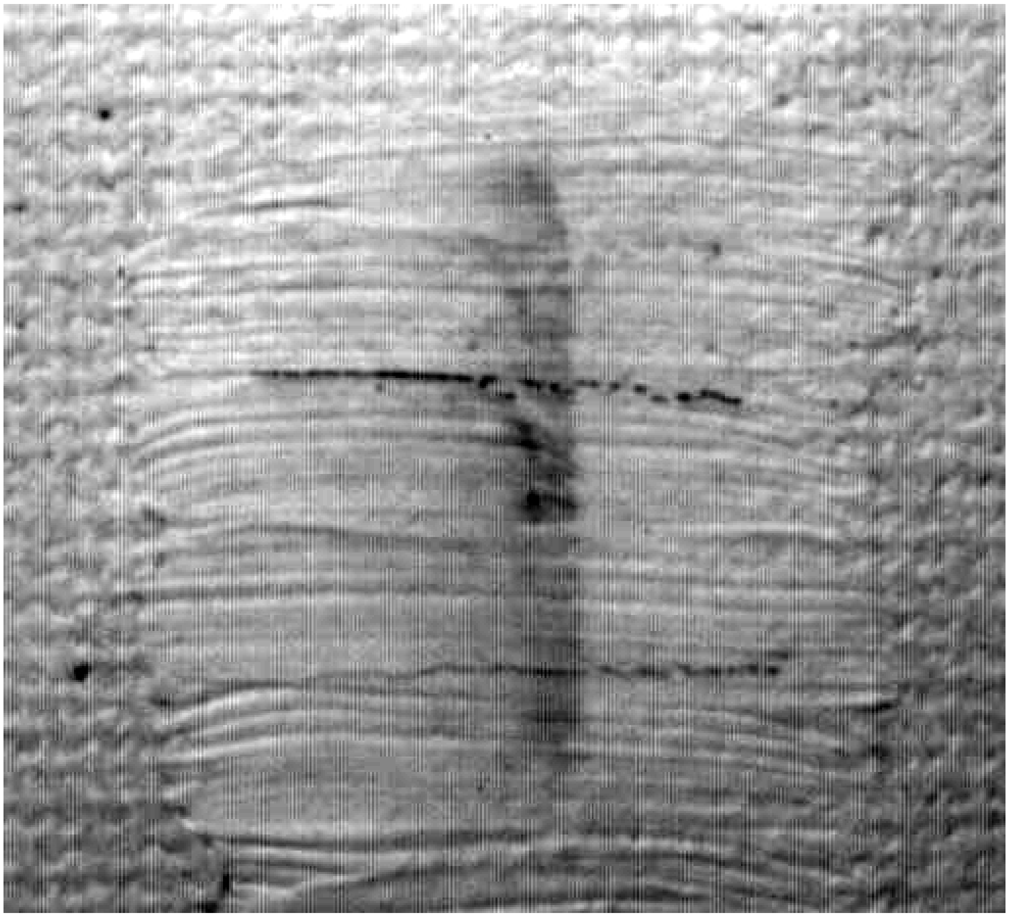

*Image R.3: Enhanced Contrast of Infrared Image (Image R.2)*

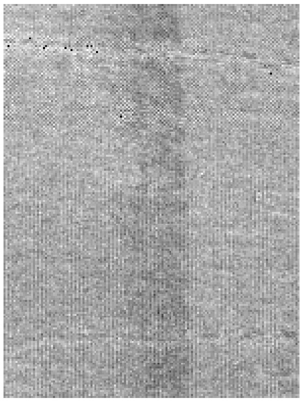

*Image R.4: Exposed Underdrawing Using Approximation Equation #1*

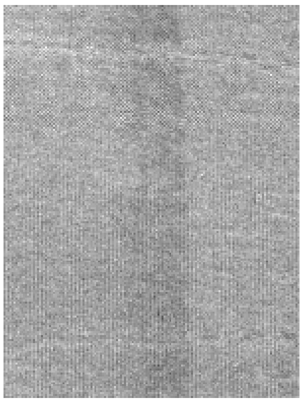

*Image R.5: Exposed Underdrawing Using Approximation Equation #2*

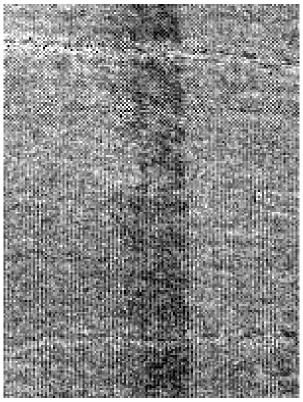

*Image R.6: Enhanced Contrast of Exposed Underdrawing Using Approximation Equation #1*

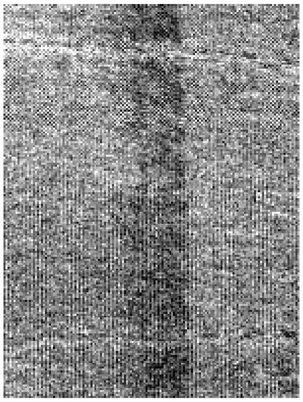

*Image R.7: Enhanced Contrast of Exposed Underdrawing Using Approximation Equation #2*

As can be seen from the images above, both Images R.4 and R.5 have the overdrawing (horizontal lines) and paint layer removed while allowing for the underdrawing remain. This is clearly an improvement over the infrared image (Image R.2). As mentioned before, most other methods have stopped their analysis with the capture of an image in the infrared region. Some will also perform minimal digital image processing such as increasing the contrast of the image. The greatest difference between the infrared image and the approximation images is that the charcoal overdrawing can be removed by the approximation equations.

# Discussion

An unfortunate problem that exists with this type of research is that it is difficult to determine an acceptable quantitative method to determine the effectiveness of these equations. Qualitatively, it should be obvious that the analysis of differences between the infrared and visible images using an approximation of Kubelka-Munk offers improvement over prior infrared reflectography methods.

Although error could have been caused by several sources during this research, there is no question that the greatest possibility for error lies in the handling of the Kodak Wratten filter 87C. This filter needed to be placed directly against the camera lens in order to allow only infrared radiation to enter the camera when capturing an infrared image. As no suitable device was available to hold the filter in a position close to the camera lens, it was necessary to hold the filter by hand. It was impossible to use both hands to keep the filter firmly in place, as one hand was needed to capture the image. Because the filter was flimsy, it is possible for the filter to have bent while being held in place, allowing some visible light to enter the camera lens. It is unlikely that the amount of stray visible light remained the same for each infrared image. As a result, it is possible that while there is some continuity between images captured in the visible region, no continuity exists between images captured in the infrared region. The amount of stray visible light would not have been enough to seriously alter the final outcome of the results, namely, the possibility of uncovering the underdrawing. However, stray visible light illuminating the infrared image would change the values for the scattering coefficient and absorption coefficient for each set of infrared and visible images. Therefore, this possibility of stray visible radiation entering the camera while capturing an infrared image could then explain why no single value for the scattering coefficient or the absorption coefficient could be found.

It is also possible that each set of infrared and visible images were not aligned with each other. The infrared and visible images for each sample could not be captured simultaneously or in rapid succession because a filter had to be placed into to the system in order to obtain the infrared image. As a result, any movement of the camera or sample during the time between the capture of the images would cause the infrared and visible images for that sample to be out of registration with each other. The possibility of this occuring was again magnified by the fact that the filter had to be inserted into the system manually. The camera aperture had to be manually opened for the infrared image due to the limited amount of radiation passing through the filter. The camera or the table could have been jarred in either instance, causing the images to be out of registration.

# Conclusions

The results obtained by this research indicate that it is possible to expose a larger portion of the underdrawing by using approximations of the Kubelka-Munk theory to evaluate the infrared and visible radiation reflected by a painting. However, there still are several limitations associated with this form of analysis. The proposed incorporation of Kubelka-Munk theory into infrared analysis does nothing to help expose an underdrawing if the underdrawing is composed of a medium that does not reflect infrared radiation. The probability of an exposed underdrawing also decreases if the overlying layer that reflects infrared radiation is of the same orientation as the underdrawing. The method will be unable to reveal the underdrawing if the entire paint layer is composed of a medium that reflects infrared radiation.

It is obvious errors did exist in this research. However, those errors did not affect the ability of this research to expose an underdrawing nor do they belie the fact that this form of analysis is an improvement over previous methods. Similarly, simple steps can be taken to remove these errors from future use of this method. Stray visible light can be removed from the system by developing a method to seal the filter tightly around the camera lens. This could be accomplished by constructing a border around the filter out of a material such as cardboard. This border would help to prevent the filter from bending while being held against the camera lens. If additional money is available an automated method could be developed to place the filter in front of the camera lens. By removing the need to manually introduce the filter into the system both the possibility of stray visible light and jarring of the equipment would be reduced. Anchoring the camera with more than one support would help to reduce the possibility of lack of registration. Placing the computer system on a separate table could also prevent any jarring of the camera equipment or sample.

The implication of this research is clear. The fact that approximations of the Kubelka-Munk theory offer a better image of the underdrawing suggests that an algorithm of the Kubelka-Munk theory should be developed for the evaluation of underdrawings in oil paintings. By evaluating an underdrawing using a derivation of the Kubelka-Munk theory it is likely a greater portion of an underdrawing will be revealed.

# Improved Acquisition Technique of Underdrawings in Oil-Paintings Using IR-Reflectography

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**References**

1. Carr,D.W. and Leonard,M.
   Looking at Paintings: A Guide to Technical Terms. J. Paul Getty Museum, Malibu. 1992.

2. Walmsley,E. (et al.)
   Evaluation of Platinum Silicide Cameras for Use in Infrared Reflectography. ICOM Committee for Conservation, 10th Triennial Meeting, Washington, D.C., 1993.

3. Real,W.A.
   Exploring New Applications for Infrared Reflectography. Bulletin of the Cleveland Museum of Art, Vol. 72, 1985.

4. Walmsley,E. (et al.)
   Evaluation of System Performance of Near-Infrared Imaging Devices. Studies in Conservation 37, 1992.

5. Asperen de Boer, J.R.J.
   Infrared Reflectography: A Contribution to the Examination of Earlier European Paintings. Central Research Laboratory for Objects of Art and Science: Amsterdam, The Netherlands. 1970.

6. Barnes,P.L. Infrared Radiation in the Examination of Works of Art. 1994.

7. Silverman,J. Infrared Video Cameras. Scientific American, March 1992.

8. Aldrovandi,A. Multispectral Image Processing of Paintings. Studies in Conservation 33, 1988.

9. Kossolapev,A.J.
   An Improved Vidicon TV Camera for IR-Reflectography. ICOM Committee for Conservation, 10th Triennial Meeting, Washington, D.C., 1993.

10. Wecksung,G. (et al.)
    Assembly of Infra-Red Reflectograms by Digital Image Processing Using a Portable Data Collecting System. ICOM Committee for Conservation, 8th Triennial Meeting, Sydney. 1987.

11. Delaney,J.K.
    Examination of the Visibility of Underdrawing Lines as a Function of Wavelength. ICOM Committee for Conservation, 10th Triennial Meeting, Washington, D.C. 1993.

12. Bertani,D. (et al.) A Scanning Device for Infrared Reflectography. Studies in Conservation 35, 1990.

13. Coddington,J.
    The Use of Infra-red Vidicon and Image Digitizing Software in examining 20th-Century works of Art. AIC Paintings Specialty Group Postprints, Albuquerque, NM. 1991.

14. Rathenau,G.W.
    Infrared Reflectography: A Contribution to the Examination of Earlier European Paintings. Central Research Laboratory for Objects of Art and Science, Amsterdam. 1970.

# Improved Acquisition Technique of Underdrawings in Oil-Paintings Using IR-Reflectography

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**List of Symbols**

| *Theoretical Equations* | |
|---|---|
| S | scattering coefficient |
| K | absorption coefficient |
| $R_o$ | reflection of an infinitely thick paint layer |
| X | paint layer thickness |
| a | $a = \frac{S+K}{S}$ <br> $a = \frac{1}{2} \cdot \left(R_o^{-1} + R_o\right)$ |
| b | $b = \sqrt{a^2 - 1}$ <br> $b = \frac{1}{2} \cdot \left(R_o^{-1} - R_o\right)$ |
| k | contrast-ratio |
| $R_{pB}$ | paint layer reflectance of the underdrawing |
| $R_{pG}$ | paint layer reflectance of the ground |
| $X_D$ | hiding thickness |

| *Approximation Equations* | |
|---|---|
| $P_{UD}$ | image of underdrawing |

| | |
|---|---|
| $P_{VIS}$ | visible image |
| $P_{IR}$ | infrared image |
| x | horizontal pixel value |
| y | vertical pixel value |
| S | scattering coefficient |
| K | absorption coefficient |
| $X_1$ | contrast variable |
| $X_2$ | brightness variable |