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Facsimile reproductions of art with the use of a digital camera system

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Facsimile Reproductions of Art with the use of a Digital Camera System

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Sciences in the College of Imaging Arts and Sciences of the Rochester Institute of Technology

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Certificate of Approval

Master's Thesis

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Abstract

Reproductions of original works of art have played a major role in the existence and growth of the graphic arts over the centuries. The one concept that has not changed over time is the difficulty in reproducing art that is true to the original. Using a high-end scanning system is one known method that is able to achieve high quality reproductions. However, it has several limitations.

The purpose of this research was to verify that a digital camera system combined with color separation software can be used as an alternative technique to create facsimile reproductions of art.

Five pieces of original artwork representing a variety of media were reproduced with the high-end system and were photographed using the Dicomed digital camera system. The two sets of reproductions were compared to the original. The comparison was in how well they matched the original.

Utilizing three standard testing procedures, there was no significant difference between the two reproduction methods. With the introduction of digital photography into the publishing environment; prepress professionals would require the skills of the photographer. Also, photographers are further exposed to the traditional separation skill of the scanner operator; obscuring the distinction between photographer and prepress professional.

A goal of the printing industry is to eliminate unnecessary steps in the process; ie, graphic arts films being replaced by computer-to-plate systems. With this goal in mind, it makes perfect sense to eliminate unnecessary steps in capturing the original image; ie, using a digital camera system.

Chapter One

Introduction

> When a painters works is reproduced in color, by what ever method, he should ask for a lively parallel to his work, not an imitation of it. He should ask for, in fact for the same kind of result he would get if he translated a work of his own into another medium.
>
> — John Piper

A facsimile reproduction is an exact reproduction or copy of the original.[1] A majority of art reproductions are not facsimile reproductions due to the great amount of time and expense derived to achieve a true facsimile reproduction. True facsimile reproductions are seldom produced and relatively expensive to purchase. For a majority of art enthusiasts, this is very discouraging.

In-direct and high-end scanning are just two methods used to achieve a facsimile reproduction. The In-direct technique is not widely used today. It is a reproduction process which requires a high level of skill and time. High-end scanning systems are the second method which can be used to achieve a facsimile reproduction. However, it also has limitations. The size of the drum determines the reproduction size. The original art must be of appropriate size to fit around the drum and flexible enough to be wrapped around the drum of the high-end system. For delicate art this process would be too harmful to the original. An alternate technique used is duplicating the original art by creating a conversion transparency. This causes two problems when matching colors of the original art to the reproduction. The

first is that a conversion transparency contains dyes in the emulsion of the photographic film which creates color shifts. Secondly, there is a certain degree of degradation in terms of color and image detail when reproductions are done from a second generation conversion transparency.

A third method not widely researched, which may be capable of reproducing a true facsimile of original art, is the use of the Dicomed digital camera system combined with conversion software. If successful, digital photography will increase the number of true facsimile reproductions available for all reproduction applications. With this method, true facsimile reproductions can be offered at a lower cost eliminating the need for film and film processing. Printers and separators who are not presently in the field can easily adapt to the digital camera system using the same reproduction criteria. Most importantly, continuous use will expedite the research of the digital camera technology improving its imaging quality and thus becoming the standard choice for all facsimile reproductions.

A famous piece such as the Mona Lisa is well known and widely reproduced in many art books, but often times reproductions fail to achieve the same gratification as viewing the original. The original art emits the aesthetic of the painter's palette and technique. Enthusiasts who are unable to view an original rely on quality book reproductions to replicate the characteristics of the original. Preconceived expectations of that original are formed based on the reproduction. Because of the difficulties in producing a true facsimile reproduction, all reproductions not produced for extremely fine quality are sacrificed. When the opportunity to view the original art becomes possible, often times a transformation of enlightenment occurs to the enthusiast. The surprise is due to the dearth of color accuracy in the reproduction.

The solution is to create and publish high quality facsimile reproductions for all fine quality applications, safely and affordably, making the original widely available to all art enthusiasts. Recently, a new method for making inexpensive and accurate reproductions has become available: direct on-site digital photography."[2] The truth about reproducing art in electronic form is that the more control you have from the capture of the images, the more probability you have of reproducing the art with higher fidelity.[3]

In 1989, the National Gallery, Berkbeck College and the University of London used all digital photography for high quality electronic images of paintings. The two most important criteria for the project VASARI: Visual Art System for Archiving and Retrieval of Images was resolution and color accuracy.

> VASARI aims to show that it is feasible to produce high-resolution digital images with accurate color directly from paintings. Digital images can record color more precisely than photographic materials and are not subject to deterioration with time. The equipment is being used to create accurate permanent record for conservation research (one aim is to use the images to monitor any changes in color or surface texture, such as crack patterns, over time), for teaching art history and the production of printed materials. Eventually it might replace photography as a recording method.[4]

In 1989 high quality camera systems were not available. VASARI used a camera system specially created for this project. Since 1989 the technology of digital camera systems has improved tremendously. High quality camera systems are now available for this specialized market offering many advantages aside from true facsimile reproductions.

Digital photography also offers solutions to museums, galleries and artists in terms of historical preservation, archiving, conserving, exhibiting, and educating. Museums today are caught in a philosophical and practical bind between protecting and preserving the original objects of great preciousness, rarity of value, and making them available to as wide an audience as possible.[5] Historically and scientifically it is necessary to view the original piece of art in order to predict the time of its creation and in some cases, discover the actual artist if the piece is unknown. Viewing art in this manner also allows the historian to comprehend the essence of the artist's creativity. By observing the detailed brush strokes and choice of pigments that skillfully composes the image, one derives a greater sense of appreciation and true representation of the artist's original palette and intention.

Digital photography can safely record rare objects directly from the original in-house without harm. A digital file of the original can be used for either historical and scientific research or for curious art enthusiasts. The digital file can be sent to special scientists around the world making it possible to observe brush strokes and surface textures while the original is safely maintained within the archives of the museum. Some systems can record images in the infrared range providing detection of the preliminary drawings under the final work, helping art historians study the original or the structure of the image. Viewing and analyzing the digital files saves wear and tear on the original image in cases where it was traditionally necessary to view the original. Digital images can also be duplicated more exactly and easily without loss of detail when compared to the original image.

Other benefits of digital photography include solutions to archiving a collection within a museum or gallery. Traditionally, a collection contained within a museum

or gallery is photographed directly from the original onto photographic transparency film. In most cases this is done by outside service bureaus (causing some consideration of the transportation of preserving the original). One of the copies is saved and stored for archiving purposes. Another is used to send for reproduction purposes. This method of creating a color transparency from the original causes several problems in reproducing a true facsimile reproduction. There is no way you can take a painting and take a piece of film and match it.[6] A color bias contained within the photographic material creates difficulties in reproducing a facsimile. Secondly, reproductions from a second generation original cause a loss to a certain degree in color degradation, image detail and resolution. Thirdly, over time the photographic materials deteriorate, and shift the colors compared to the original, thus making a facsimile reproduction virtually impossible to reproduce. Oftentimes, the collection needs to be rephotographed periodically to avoid deterioration.

> Digital technology has permitted museums to store images without worrying about a photograph's color degradation, image detail, or loss due to the lack of duplicates. While color in photographs degrades over time as the chemicals break down, digital images retain the original value.[7]

New technology should be at least as good as what it replaces. The new breed of digital cameras have definitely proven that they can produce images equal in quality to conventional photography.[8]

Chapter One Endnotes

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Chapter Two

Theoretical Basis of Color Reproduction

It is necessary to understand color reproduction principles because they underlie all color reproduction systems in today's technology. It is the main concept in understanding how television, monitors, photography and printing presses reproduce an image.

The characteristics of the human eye are the source copied by technology to create and match colors of an original by controlling the intensities in a mixture of only three lights. Given the respective sensitivities of the human eyes color-sensitive cells, it turns out that various mixtures of red, green and blue lights create the widest range of perceived colors. For this reason, all color reproduction systems operate by controlling the intensities of red, green and blue light reaching the eye from each elemental area of the picture.[1] Each system aims to control the amount of the RGB light intensities to reproduce a color image. The nature of the technology and its medium dictates the various means of controlling the RGB light intensities.

The Printing Process

The various printing technologies available today such as letterpress, gravure, flexography, screen and offset lithography vary in technique but are similar in that they are all based on the principle of three subtractive primaries (cyan, magenta, yellow)

and black creating the illusion of thousands of colors contained in the original. Offset lithography is the preferred method for facsimile art reproduction because it is cost-effective and has the ability to create fine quality reproductions on various substrates.

Regardless of the printing method used to create a facsimile art reproduction, the concept of breaking down the original into the necessary color components is essential to the printing process. In-direct, electronic and desktop color separations are the three options which exist to break down the original to create halftone color separations. Endangerment to the original, the precautions taken needed to preserve and the physical makeup, are issues dictating the color separation process and technique used. Direct use of the original art combined with a skilled and knowledgeable operator is always optimal to produce a facsimile reproduction. Direct use of the original eliminates the deterioration of detail and resolution from second or third generation photographic duplicates. It also reduces the chance of color shifts caused by the characteristics and development of the color photographic film process.

In-Direct Separations

This is a photographic method originated in 1890 and is still in limited use today. The technique uses a graphic arts camera with three separate exposures through red, green and blue colored filters creating cyan, magenta, yellow and black separation films. For example, the red filter is placed over the lens of a graphic arts camera to record all the red light information reflected or transmitted directly from the original creating the cyan separation film. This negative film records all the red

information in various densities. The process is repeated using the green and then the blue filter. These film negatives are then used to produce the halftone images required for the printing process. The size of each halftone dot on the film reflects the darkness or density of the image at that point in the original. Other applications such as unsharp masking and color correction are separate steps that a skilled operator factors into the process to create a set of separation films which will reproduce a facsimile reproduction. The photographic separation method dominated color production for many years, but in the past two decades, it has largely been replaced by electronic scanning, which itself is now being supplanted by desktop color separations.[2]

Electronic Separations

Companies like Scitex, Crosfield, and Linotype-Hell emerged in the 1970's and 80's inventing high-end scanning systems redeveloping halftone technology. These high-end systems create halftone separations electronically by forming halftone dots on film by individual printer spots. The main difference between a camera and a color scanner is the camera records the entire picture at one time. The color scanner records at a high speeds, tiny segments of the original. The input end of the scanner consists of a clear drum with a transparent or reflective light source to scan reflective or transparent originals. The original is mounted to the drum of the scanner. A photographic transparency of the original artwork, or if possible the original art, can be mounted around the drum if its physical characteristics are flexible and the media is in no danger of destruction. In most cases, the method used to reproduce old and delicate works of art is by photographing the original onto 4x5 or 8x10 transparency film and making the separations from this photographic material.

The drum revolves at extremely high speeds around the light source as it illuminates the original. The light is channeled to an analyzing head containing microscopic optics which split the light into three or four beams. The intensity of each beam is measured by photomultiplier tubes (PMT) covered with red, green and blue filters. The fourth beam activates a PMT used to compensate for loss of detail by unsharp masking electronically. The PMT converts the light into electronic signals in proportion to the light it received.

The color information from the RGB electronic signals are calculated from the color computer by the manufacturer's proprietary algorithms into cyan, magenta, yellow separations. A black separation is created as a subsequent step based on the information from the cyan, magenta and yellow signals. For every scanned spot on the original, the RGB electronic information relative to the scan spot is instantly converted into CMYK to produce the proper halftone dot on film. After the scan is complete, the film is ready for processing to produce all four halftone color separations.

> The scanner operator can apply under color removal when desired and can modify standard tone reproduction curves to meet specific printing conditions. These improvements make color separation by scanning faster than handwork and, depending upon operator skills, more predictable. A good scanner operator is essential because the operator must interpret the copy and make the judgements necessary to scan the copy for the paper and inks to be printed.[3]

The color scanner offers greater flexibility and speed than photographic methods because it combines several time-consuming steps that must be done separately with a camera. The scanner "in real time" or "on the fly" combines color-masking,

color separation, screening, corrections for ink deficiencies and editorial changes to the original to produce personalized separations.

Desktop Color Separation

> The challenge of software developers was to encapsulate decades of color separation methodology in their products. Once this was accomplished, experts were able to produce quality color separations from the desktop. But what the market really needed was a system that provided quality color reproduction with push-button ease.[4]

> Until the technology of desktop publishing rivals the ease of office copiers, skill and fundamental understanding will be needed by users if they are to begin to realize the full potential of desktop publishing.[5]

Working in a desktop environment, the difference between good color separations and poor color separations is entirely dependent on the capability of the systems components and software, as well as the skill and experience of the operator. Most desktop systems use CCD technology which captures the image in RGB format (excluding midrange drum scanners using PMT technology). Color separations must take place later in the production process on the desktop computer with the use of color separation software. How the color separation from RGB to CMYK takes place is crucial to output quality.[6] Color management applications assist in this process, however, the same skills and knowledge used on a high-end system are also required in the desktop environment. Once the RGB image is separated into CMYK format the image is sent to a Raster Imaging Processor to generate halftones electronically. The information is exposed onto film using an image setter. The photographic films are processed to produce a set of halftone separation films. In-house separations can be performed, reducing the cost of an outside service; plus, greater control is obtained over the separation process, separation software

enables fine-tuning the formulas to convert images from RGB to CMYK. One major disadvantage is productivity—high-end scanners perform separations with specialized hardware in real time.[7]

> All three methods can produce high quality when they are used by a knowledgeable operator, and it's to say unequivocally that one is better than the other. The factors that make color separation by electronic and desktop tools dominate have much more to do with economics, speed and user control than with quality.[8]

Color Reproduction Requirements

> A traditional graphic arts scanner may have dozens of knobs and dials, or even more digital settings, to manipulate the appearance of a color separation. Systematic scanner set up is necessary for consistent high-quality color reproductions. Color reproduction requirements are criteria for evaluating and adjusting color separations for accuracy and consistency. These requirements are the same for any color reproduction system, whether a graphic arts camera with color filters, a high-end color scanner or a desktop scanner and computer system.[9]

Regardless of the system or technology used, the key in producing accurate and consistent reproductions is relative to the capability of the system combined with the operators experience, skills and knowledge in the basics of color reproduction. The criteria for good color reproduction consists of tone reproduction, gray balance, color correction, and detail enhancement.

UCR & GCR

Under color removal (UCR) and gray component replacement (GCR) are not part of the basics of good color criteria, however, it is part of the reproduction process used both in high-end scanning as well as on the desktop and should be understood. UCR and GCR remove equal proportions of cyan, magenta and yellow and replaces it with a corresponding amount of black. Both UCR and GCR perform similar functions but each affects different areas in the original. UCR removes percentages of cyan, magenta and yellow in only the neutral areas of the image. GCR removes percentages of cyan, magenta and yellow in neutrals and desaturated color areas replacing it with a corresponding amount of black. The resulting reproduction when applying UCR or GCR should look the same when compared to a final reproduction that didn't apply UCR or GCR. The benefits of applying percentages of UCR or GCR in the reproduction process is that it eliminates excess ink coverage, minimizes registration problems, controls dot gain, faster drying times, and maintains neutrality on the press. Too much of either method can cause the image to appear too grainy and reduce the density the of darker colors.

Tone Reproduction

Tone reproduction is the relationship of the density in the original to the percent dot printed in the final reproduction.[10] In order to reproduce the most pleasing match in terms of contrast, it is essential to select the correct halftone dot placement for the highlight, midtone and shadow areas. To achieve proper tone placement on the desktop, the tone characteristics of the digital image are adjusted through software to compensate for the dot gain in the reproduction process. Dot gain is the enlargement of the halftone dot created by image transfer and ink

absorption into the paper. The result of dot gain is a change in image control and tone value of the printed image. It is important to realize a normal contrast original contains a greater density range than the printing process is capable of reproducing, thus tones in the original must be sacrificed. Tone compression is necessary in the less important areas of the original. The adjustment in the halftone process is needed to give the tone reproduction of the printed image the appearance of matching the tones and tonal range of the original.

Gray Balance

In 1869, Louis Ducos Du Hauran pointed out the necessity of adjusting the screen by such an arrangement of elements that it would appear gray and show no excess of any color whatsoever.[11] CMY process inks contain spectral impurities from unwanted light absorption. Equal amounts of cyan, magenta and yellow when overprinted produce a pinkish brown color. These impurities, if not corrected by a scanner adjustment, can cause a color cast in the neutral area of a reproduction. Gray balance is obtained when the right combinations of cyan, magenta and yellow dot sizes are used to reproduce a neutral gray scale with the printing inks at a certain density for each ink.[12] More cyan is generally required to obtain neutral. Gray balance should be altered for specific ink sets. Fine tuning must also be accomplished for several types of dyes contained in the original. Once gray balance is obtained, theoretically, the reproduction system can accurately reproduce the color of the original.

Color Correction

Color correction is important for the best reproduction regardless of the substrate and inks used; to optimize the reproduction of different emulsions; and to change colors according to customer preference.[13] The color reproduction requirements are interdependent, representing a sequence from coarse to fine tuning.

As explained in the description of gray balance, process inks are impure. No process ink has the ideal characteristic of one-third spectral absorption and two-thirds spectral transmittance.[14] Along with gray balance, color correction further counteracts the deficiencies in the ink set used. Further adjustments can refine the different dyes contained in the substrate of the original.

Editorial changes are another important use for color correction. Clients, for advertising purposes or to compensate for a bad original, will desire color changes to meet their specific needs. Global correction compensates for overall changes in the original. It affects every color in which the changed color is needed to make that hue. For instance, if an adjustment is made to magenta, it will affect pink, red, orange and purple. Selective color correction selectively corrects the color of specific hues contained within the image. If another color contained within the image has a similar color combination, the change will also affect that color.

Detail Enhancement

Detail enhancement utilizes unsharp masking (USM) techniques, increasing the apparent resolution and detail of an image. This is necessary to offset detail lost when separating a high-quality original into a series of halftones.[15] Detail enhance-

ment is dictated by the nature of the original. Too much detail enhancement can cause an image to appear coarse and grainy. Detail enhancement does not add detail to an image. It is an optical effect that accentuates the contrast between adjacent tones increasing the edge effect where the tone changes.[17] This effect gives the appearance of a sharper image.

Chapter Two Endnotes

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Chapter Three

Research in the Field of Digital Photography

Digital photography was first introduced in 1985 and was not considered much of a threat to traditional film photography. At that time, digital camera systems were expensive, not adaptable to conventional photographic equipment, and required the use of a still video floppy disk to record the captured images. A still video disk could record 25 to 50 low resolution files suitable for newspaper reproduction or for monitor and television screen display.

In the past ten years, the charge coupled device (CCD) technology used in digital photography has improved tremendously in its capabilities to capture more information, thus appealing to a wide variety of markets. Digital photography has expanded its use in photojournalism while branching into many levels of advertising and consumer applications. A variety of digital cameras have been designed specifically for each application, utilizing the best workflow for that application.

Today, digital cameras continue to slowly erode the use of traditional film. A recent survey by Eastman Kodak has shown in the last five years digital photography has grown approximately 15%. As the quality of the digital camera continues to increase, an estimated 5% per year decrease is expected in applications of traditional film photography.

Digital Photography Technology

All digital cameras function with the use of CCD technology which consist of evenly spaced photosensitive detectors which convert light into an electronic signal. CCD's are compact and lightweight; they consume little power; they are readily mass-produced with standard semiconductor fabrication methods, and they are reasonably sensitive to visible light over a wide range of intensities.[1] They are intrinsically monochrome devices extremely sensitive to infrared light as well as having a strong sensitivity to the red end of the spectrum. Filters or dyes are placed over the CCD's to compensate for the bias in sensitivity for producing color images.

The cost of a digital camera can range from $750 to $54,000 based on the high cost of manufacturing CCD chips. The number of CCD's within a digital camera directly corresponds to its cost. The number of pixels (picture elements) contained within the image area, defines the resolution capabilities of the camera system. Digital camera technology is offered to a variety of markets while keeping costs respectively low by correlating the needed number of CCD's within the camera for its intended market.

Based on the requirements of the market, CCD chips can be arranged in a linear, tri-linear, or area array. A linear array contains a single row of many CCD's. A scanning head containing a linear array captures data by travelling across the image area, building the image up in pixels one row at a time for a monochrome image. The scanning time can take several minutes which would eliminate its use with moving objects and strobe lighting systems. To

capture the color information of an image, it takes three passes. One pass with a red filter, the second with a green filter and the third with a blue filter, thus increasing the scanning time. One benefit to this system is that it can contain a higher number of CCD's in a row to achieve high image resolutions.

A tri-linear array is composed of three linear CCD's attached to one another side-by-side. A red, green or blue color filter is embedded over one of the three rows of CCD's capturing the color information. It captures color image data with a single pass by each linear CCD scanning one line at a time. Software combines the interleaved color planes creating the final color image. The scanning time is reduced compared to a linear array system, however the scan time can still take several minutes. This CCD design also eliminates its use with moving objects and strobe lighting systems since the scanning head is continuously capturing information. Scan back cameras utilize the benefit of a tri-linear design to produce very high resolution images although this system requires a strong, continuous, stable photographic light source.

An area array contains a two-dimensional matrix of CCD's. Each CCD within the area array contributes to a single pixel within the image which defines and limits the resolution capabilities of the camera system. The image data is captured with one exposure using similar camera settings for film as well as conventional photographic lighting for a monochrome image. To capture color information, two alternate technologies can be used with

this design. The first is similar to the linear technology. The image data is captured through a red, green or blue filter with three separate exposures through alternate filters. Software used with the camera system combines the three exposures creating a full-color image. Since three exposures are necessary, exposure time is increased and movable objects are unable to be photographed. A strobe lighting system can be used because the image is captured three separate times with the same exposure.

The second technology uses a striped array of red, green, and blue dyes placed on the surface of individual CCD's contained within the area array. Image data for each pixel is captured in only one of the three colors. The software calculates the alternate color information by averaging the adjacent pixels. This can cause artifacts in images if fine details fall on only one of the CCD elements, because no color information can be calculated from the adjacent pixels. The benefit in using this type of a CCD design is that one exposure is required. This offers real time image capture with similar exposure times and conventional photographic lighting for live action or still life images.

A moving CCD area array is another configuration of CCD's. An entire array is mounted on piezoelectric crystals which can move a precise distance in response to an applied voltage. It captures several partial images moving in small precise distances. The image is captured by computer software which composites the partial images into the final color image.

A final variation of CCD configuration involves splitting the incoming light onto three area arrays through a prism contained within the camera. Depending upon the configuration, either a single color per array can be used or two of the arrays are dedicated to green, with the third array split between blue and red. This design arrangement produces very sharp details and is designed based on the greater number of green receptors in the human eye.

Digital camera systems are utilizing each of these technologies for studio, field or consumer markets. Studio photography is the most mature market area for digital cameras.[2] Generally, it is not a camera but a digital element that is adapted to conventional photographic equipment. A majority of studio photography is produced with a 4x5 view camera; a digital camera element is inserted in place of the traditional film holder capturing the image digitally. Ideally, it still functions like film; however, digital backs generally require a strong, continuous light source. Strict lighting requirements and the inability to capture moving subjects are a couple of the major drawbacks of the scan-back camera, but its primary advantage is high resolution.[3]

Field cameras are the hottest area of digital photography,[4] having a similar look and feel to traditional 35mm cameras. These generally use a striped CCD area array. Field cameras are in high demand for photojournalism applications since they can photograph action or still life images with conventional photographic exposures.

There is a new generation of digital camera that is offered to the consumer market. If image quality is a concern, you are better off spending your money on a modern point and shoot 35mm camera . . . the appeal of the consumer digital cameras is the speed and ease with which you can bring images to your computer and—dare we say it?—a love of gadgetry for its own sake.[5] These cameras operate similar to a point and shoot camera with crude controls for exposure and with limiting resolution capabilities. This style of digital camera is generally not suitable for a publishing environment and is used primarily used for educational and consumer purposes.

Considerations with Digital Cameras

CCD technology is not capable of capturing the full resolution or color depth compared to traditional film. Thus several factors should be considered and understood for each application in order take full advantage of the current technology without any frustrations or preconceived expectations. As with conventional photography, results will vary depending upon the system used. Digital camera systems produce optimum results when all the considerations of working with a digital camera system have been factored.

Resolution capabilities and the CCD arrangement within a camera system is of great concern for determining which camera system is best suited for specific applications. As stated previously, the resolution is determined by the number of CCD's contained within the camera system. If a high resolution is not needed for a specific application, purchasing a camera system which contains the largest number of CCD's would be useless as the application

would not benefit from the full capabilities of the camera system. The arrangement of the CCD's can greatly improve the resolution, although certain CCD arrangements may not necessarily be suitable for certain applications. For example, a camera system that contains a CCD area array is limited to the number of CCD's due to the restriction of optical limits. One of the benefits of this CCD arrangement is that one exposure is needed using conventional photographic speeds. This also allows the flexibility for photographing still life or action images needed for photojournalism.

Tri-linear array systems can contain a larger number of CCD's since it is determined by a tri-linear row of CCD's and the other dimension is derived by the number of units sampled as the head travels across the image plane. This is suitable for situations that demand high resolution such as advertising and publication reproductions. This system is limited to photographing still-life images.

Cost is another factor to consider when expanding into the digital photographic realm. As the cost of the camera systems increases, so do the numbers of pixels, and the opportunities for miniaturization (which has steadily improved the price performance ratio of other semiconductors) are restricted by basic optical limits.[6] Not only is the price of the camera a consideration but also the equipment needed to produce the final image such as: a computer, software, storage capabilities, and lighting equipment.

All digital cameras require the use of a computer system to view, download and edit. The cost of software utilized for editing and manipulation varies because it is dictated by the applications environment. For example, news agencies may only need software for pagination purposes while an advertising agency needs extensive image manipulation software. To convert the RGB image to CMYK separations, color separation software is needed.

External storage is the biggest cost concern in archiving images. Digital camera systems contain their own limited hard drive space for short term storage. Once the camera's storage capabilities are full, digital images can be viewed instantaneously as the image is captured or downloaded with software and viewed at a later time. The best images can be selected and saved onto another storage device, deleting all other images making the short-term storage available to re-image.

In a production environment, file management and cataloging is a major issue. Some studio camera systems also require a special continuous light source, adding to the cost for a studio photographer adapting to a digital camera environment.

The physical size of the CCD can cause a great concern. The principle is this: the light gathering area of the CCD (or in a scanning array, the area that the CCD sweeps) is the equivalent of a sheet of film.[7] The relationship between the focal length of the lens is directly related to the diagonal measurement of the film. For photographing a general scene, a normal lens on a

35mm camera has a focal length which measures 50mm. For a 4x5 view camera, the diagonal measure of 145mm would require a longer focal length lens to fill the frame with the same composition. Telephoto lenses, which have a longer-than normal focal length, fill the frame with a smaller portion of the scene; and wide angle lenses have a shorter focal length.[8] In all instances, digital cameras have smaller CCD dimensions compared to the film they are replacing. This causes an effect called focal-length magnification. As a result, digital cameras behave as though a smaller piece of film has been loaded—or as though a longer lens has been mounted.[9] Photographers who are familiar with the effects of certain lenses need to compensate for the change in focal length on a digital camera system.

It is extremely important when using a digital camera system in a production environment, to obtain the knowledge of color conversion or color management issues. Don't be surprised if color management also becomes an increasingly important concern—for you and not just your service bureau—when you use digital photography.[10] All digital cameras capture and create images in the RGB color space which is useful for viewing images on computer monitors. The original RGB file must be compressed through software applications and then converted into a CMYK color space in order for the image to be reproduced with traditional printing techniques. Any RGB colors contained within the original that fall outside of the CMYK color space are compromised to obtain the best possible match capable of the color management or conversion software. Great knowledge and experience of the color separation process is required to reproduce quality images.

Better software applications allow an experienced operator to dictate and control the separation process to achieve the best possible match to the original. "We don't currently have a plug–and–play push–button color management system that links the digital camera to the final output."[11] Color conversion technology for the desktop environment is improving making it easier for digital images to convert into the CMYK color space without having a great deal of knowledge of the separation process.

The greatest concern when using a digital camera system is dealing with the hazards of a disk crash. If a back-up storage device is not utilized, image archiving and cataloging can be disastrous. There are several benefits in making duplicates of digital files compared to traditional film techniques. Making duplicates of an original digital image is less expensive and time consuming due to the elimination of film exposure and processing time. Duplication of an original digital image retains the image information and resolution of the original image. With traditional film techniques, image information and resolution is lost and destroyed by imaging second and sometimes third generations.

Benefits of Digital Camera Systems

> Publishers dealing with time-sensitive material—whether it be competitive advertising, breaking news, or just a smoother workflow that more effectively meets production—really benefit from the nearly instant capture of images from the camera into the computer. Others who rely heavily on an outside provider for scanning services report an impressive financial benefit to using digital cameras.[12]

Speed is the biggest advantage when working with a digital camera system for situations that require fast and demanding deadlines. Having the capabilities of instantaneous capture eliminates both the cost and environmental concerns of instant film, while still controlling lighting adjustments. Once the exposure and lighting is determined, cost-savings and environmental concerns from chemicals in the film development process is eliminated. Production time is saved in three areas: film no longer needs to be processed, editing usable images is quick and scanning time is saved since it is automatically captured in a digital format.

Service bureaus and studio photographers who use 4X5 camera systems can easily convert their camera equipment into a digital environment. A new camera system is not necessary since studio digital camera backs replace the film holder in all 4X5 camera systems. However, additional costs may need to be factored in for the studio environment. Strong continuous light sources such as high frequency fluorescent lights or HMI lights are optimum for some studio camera systems, but all require additional external storage space.

Chapter Three Endnotes

[1] Dyson, Peter, et al. *Digital Cameras for Studio Photography.* Pennsylvania: SEYBOLD Publications, 1995: 5.

[2] Fraser, Bruce. "Photo Opportunities." *Mac User* (November 1995): 86.

[3] IBID: 86.

[4] IBID: 91.

[5] IBID: 96.

[6] Dyson, Peter, et al. *Digital Cameras for Studio Photography.* Pennsylvania: SEYBOLD Publications, 1995: 11.

[7] IBID: 12.

[8] IBID: 12.

[9] IBID: 12.

[10] Borzo, Jeanette. "Eliminate the Negatives." *Publish* (November 1995): 58.

[11] IBID: 58.

[12] IBID: 54.

Chapter Four

History of Color Reproduction

"Color reproduction problems are as old as color reproduction. Reproducing art is an imprecise science."

— Mark Pollard
Director of operations at Pace Wildenstein

In the early 18th century, a three-color principle for facsimile color reproduction was developed by J.C. Le Blon. The process of a three-color approach was not unusual for this time period since Newton's theory of light was fully realized during this century. The chief legacy of this process was the inking of separate plates with the three primary colors and their successive printing. Le Blon was known as a miniature painter experimenting with printing in color. He founded a company called "The Picture Office," which consisted of a work force of engravers, colorers, printers and framers. The intention was to provide color reproductions of the old masters including the Carraci, Titian, Correggio, and Van Dyck.[1]

In 1721, Lord Percival, a shareholder within the company, wrote excitedly to his brother about the process claiming, "Our modern painters can't come near it. . . with their colors, and if they attempt a copy make us pay as many guineas as now we have shillings."[2]

Unfortunately, Le Blon was removed from his post as director being accused of illegal business practices. He was forced to move to Paris. In 1758, the process was no longer used, however, both France and England adapted similar methods to reproduce art work.

The French used a series of plates creating a difficult task of registration, as well as the selection of appropriate inks that would work well superimposed together in the printing process. A surviving manuscript note entitled "Le Pastel en Gravure invente et execute par Louis Bonnet 1769" accompanied a set of progressive proofs of "Bonnet's tete de Flore", printed from eight plates, records which colors he used and in what order and with what intention. It shows an intricate and time-consuming method if the effect were to compete in color range with the original.[3]

The English preferred the inking of a single plate with several colors in one operation. The printer referred to a standard colored copy of the original while applying the appropriate selection of inks onto a single plate by hand. This process enabled the subject to be copied freshly for each impression. This laborious process is best described by Susan Lambert in her book, "The Image Multiplied".

> The colors were dabbed on with rag balls on the end of a stick, a method of inking which became known as inking a la poupee because of the resemblance of the dabbers to rag dolls. The printer had first to decide on a ground tint, usually brown, black or gray, according to the generally prevailing tone and the plate was inked with it as if to print a monochrome impression but then wiped off so as to leave only a

> very slight residue. 'This slight tone' according to Mrs. Frankau, who based her statements on the folklore of color printers still working at the close of the last century, 'dominated the picture, lightened or deepened the plate changed the relation of all the colors, and affected the ultimate result in every detail. The printer then applied the other broad areas of color before turning to the flesh tints which required a different ground from the rest of the image if they were to have the same depth of modeling but not look muddy. Over 'a ground of carmine and white, or carmine and burnt sienna, or carmine alone, or blue and white or a hundred other combinations, the effect which had to be laboriously sought, the flesh had to be built up, the features, eyes and brows, shadows and lips' painted into the plate. During all this work, the plate had to be kept warm enough to keep the inks viscous, but not so warm as to make them run. Before the plate was printed all the tints had to be blended in at their points of contact and the surface of the plate had to be wiped clean so that the ink was held only in the hollows. The intricacy of the coloring and therefore its possible closeness to the original depended on the printer's skill and the time he was allowed for the 'painting-in' process. The number of impressions produced a day was, inevitably, small.[4]

Both methods were extremely tedious and could not meet the requirements of mass production. However, a market for facsimile reproduction was discovered. That there was a market for colored reproduction that was closer to the appearance of oil paintings is suggested by the establishment of the Polygraphic Society, which held its first exhibition in 1784 and displayed the original paintings beside the reproduction.[5]

The Polygraph was a process developed by Joesph Booth which claimed to multiply pictures in oil colors with all the properties of the original paintings; whether in regard to outline, size, variety of tints and included a canvas support. Very little is known about this process and remains an enigma today.

In 1837 Engelmann, a French lithographer, invented a process and coined the term chromolithograph. He was granted for his invention a ten year patent for printing lithographs in color. Lithographers had used color in the past only to embellish a black-and-white image rather than using color as a means of duplicating the color of an original reproduction. His process was based on the knowledge of Le Blon's concept of the three primary colors. During the second half of the century, large numbers of brilliantly colored lithographs reproducing old and modern masters were produced, sometimes from as many as twenty five lithographic stones. It was the development of this process that was responsible for the creation of the printing structure that shifted from being essentially the work of an individual with the status of an artist/craftsman, to that of an industrialized team contributed to by workers who saw themselves as technicians.[6]

The color lithograph developed along side of the photograph which created some controversy. The photograph had the capabilities of reproducing the original accurately in monochrome. The debate from the Arundel Society was either to restore the originals to their former state or to show the distress of the original caused by time and neglect.

J.N. Niepce in 1827 had strived since 1813 to fix an image by light. He achieved his goal by incorporating the principles of photography to the production of a traditional printing surface. His method started by making an etching translucent by applying wax to the surface and placing it onto a metal plate. The plate was coated with a substance that hardened when

exposed for a long time to a strong light source. Upon removal of the etching, the coating had hardened where it had been exposed. Unexposed portions of the plate were protected by the lines of the etching and caused the coating to be soluble so it could be washed away. Bare metal was exposed where the lines had originally been, reproducing the exact details of the design from the original. The metal plate could then be etched and printed in the traditional manner. The drawback to this method for facsimile art reproduction is that it destroyed the original!

Further development of several photographic processes helped the public become accustomed to this form of reproduction. Delacroix, a supporter, was compelled to point out that photography showed up imperfections masked in the presence of the original by the impact of its color and the bravura of its handling.[6]

In the 1870's, a photo based printing technique called the Callotype was invented using a gelatin film as the printing surface. It was dependent on the fact that light-sensitized bichcromated gelatin hardens in proportion to the amount of light to which it was exposed and accepts ink in inverse proportion to the moisture it retains.[7] This was the last continuous tone process developed specifically for reproduction, and the first photographic process to provide high quality color reproductions of the Old Masters.[8] Since the gelatin printing surface was soft and fragile, it was unable to produce a high yield. In 1909 the Burlington Magazine said of this process, "No feat of facsimile imitation is beyond the power of this Medici process."

The invention and introduction of cross-line screening in the 1880s automated the reproduction process. Cross-line screening regulated the representation of tone by utilizing a system of dots. The glass crossline screen was the first halftone process. It was easily adapted to intaglio plates, relief printing, and the photogravure press. In 1895, The Rembrant Intaglio Printing Co. was established to print reproductions with the rotary gravure process. Color reproduction with this method still required the application of color ink by hand to the photographically produced plates.

Letterpress was another process developed in the 1880's pioneering the photomechanical, three-color, halftone relief printing process. Halftoning enabled the realistic shading of images through various dot sizes. The image area is raised above the non-printing area. Ink is rolled across the top of the image area and then transferred to the substrate. Color needed to be applied by hand.

Lithography was a process developed by Senefelder in 1798 for the facsimile reproduction of fine line drawings with exquisite detail and tone reproduction. The technique was also used for the reproduction of paintings, particularly from public collections with great tonal range and richness.[9]

The skilled printmaker drew or painted the original design onto a porous stone using a greasy substance. The stone was washed with water and then inked. The grease repelled the water in the image areas, while the ink covered the image areas to be reproduced. Later in 1875, this technique was

modified to an offset process to print on tin. The offset process first transferred the image onto a rubber cylinder instead of the substrate. The impression from the rubber cylinder was then transposed to the printed surface. It wasn't until the 1890's that this process was adapted to print on paper substrates in order to compete with the speedier rotary machines of this time. The flexibility of the cylinder allowed the use of 'any class or type of paper. . . hard, plain hand made-papers, as well as soft-sized, machine made, even 'crocodile marked and fancy ribbed,' giving lithography an advantage over letterpress for which coated papers were essential.[9]

> The invention of Lithography at the end of the 18th century, capable of reproducing the inherent textures of any of these printed media as well as the effects of the full gamut of drawn marks, more or less put an end to this ingenuity. Aspirations towards facsimile reproduction of drawings were issued in ever greater numbers. But although the technique was the conveyor of some remarkable productions, the ease of execution, made the prize not worth having. The real challenge for lithography was the reproduction of color rather than line, and the attention to the latter often slipped so far that so-called facsimiles of monochrome drawings were poor in quality, just at the time when public expectation had risen. Whatever inherent power lithography as a facsimile technique, by the last quarter of the 19th century it was simply outclassed by the near perfection achieved with the help of a camera.[10]

Still available today are modified versions of letterpress, photogravure and lithography. Although the printing techniques are similar to their ancestry, the facsimile reproduction method from the original piece of art has evolved. The advancement of technology introduced new methods enabling more accurate facsimile reproductions with less time consuming processes compared to earlier methods.

Chapter Four Endnotes

[1] Borzo, Jeanette. "Matching the Masters." *Publish* (June 1995): 87.

[2] Lambert, Susan. "The Image Multiplied: five centuries of printed reproductions of paintings and drawings." London: Trefoil Publication, 1987: 88.

[3] IBID: 88.

[4] IBID: 88.

[5] IBID: 97.

[6] IBID: 108.

[7] IBID: 110.

[8] IBID: 77.

[9] IBID: 90.

[10] IBID: 106.

Chapter Five

Hypotheses

A true facsimile art reproduction is an exact replica of an original piece of art. Unfortunately, many art reproductions are not facsimile reproductions as a result of variances in color accuracy. Methods such as the In-direct separation technique and high-end scanning systems are capable of producing a facsimile reproduction, however, they both have limitations.

In-direct separations are in limited use today because it is labor intensive and expensive. A high-end scanning system is limited to the drum size and flexibility of the original art. In addition, a conversion transparency of the original art can be used, however, it is a second generation duplicate. This causes difficulties when matching the color of the reproduction to the art, increasing the price of a true facsimile reproduction. Duplicating the art into a color transparency or a conversion transparency causes colors to shift based on the dye colorant contained in the emulsion of the photographic film. Reproducing from a second generation conversion transparency also causes degradation in image detail and resolution compared to the original.

A third reproduction method is suggested for the reproduction of art by this researcher. The use of the Dicomed digital camera system and desktop separation software, could be an alternative for facsimile art reproductions. The objective of this research was to verify that the Dicomed digital camera system, in conjunction with desktop color separation software has the ability to produce a facsimile reproduction of art that is equal in quality when compared to current reproduction methods. Success will be dependent on the camera system, the color separation software, and the ability to adjust the process in terms of tone reproduction, gray balance, color correction and detail enhancement. The challenge of this thesis is to use this system to obtain a high quality facsimile art reproduction and to succeed in an area where digital camera systems are not widely used.
Advantages in using a digital camera system for art reproduction include:

- Safe handling and preservation of valuable and delicate art work since the prepress process can be executed directly in-house.
- Reproductions are made directly from the original art which reduce the loss of detail and color accuracy.
- Elimination of periodically recreating conversion transparencies of artwork for archiving and reproduction purposes.
- The reproduction of large art and delicate art which are unable to be reproduced directly from a high-end drum scanner.

- Cost saving benefits from the elimination of film and processing.
- Increases in productivity due to the elimination of film processing.
- Files are automatically created and ready for use, saving the cost of relying on outside sources for this service.

If a digital camera system in conjunction with desktop color separation software is proven to be successful, it will introduce a new technique for facsimile reproduction to the graphic arts industry.

Null Hypotheses 1:
The Dicomed digital camera system when combined with desktop color separation software, can produce a facsimile art reproduction in terms of color, tone reproduction gray balance and detail.

Alternate Hypotheses 1:
The Dicomed digital camera system when combined with desktop color separation software, cannot produce a facsimile art reproduction in terms of color, tone reproduction gray balance and detail.

Null Hypotheses 2:
The Dicomed digital camera system when combined with desktop color separation software, can produce an art reproduction at the same quality level as art reproduced from a high-end color scanner in terms of color, tone reproduction, gray balance and detail.

Alternate Hypotheses 2:

The Dicomed digital camera system when combined with desktop color separation software, cannot produce an art reproduction at the same quality level as art reproduced from a high-end color scanner in terms of color, tone reproduction, gray balance and detail.

Chapter Six

Methodology

Methodology

For a more detailed description of the testing procedure please see appendix A, pages 69 through 74.

1) Artwork was collected from various artist representing a variety of media such as oil and acrylic paintings, watercolors and pastels.

2) The artwork was sent to Litho Inc. in Minnesota to reproduce the five originals directly on a high-end scanning system and digital imaging workstations. Individual specification sheets for each image was recorded noting the adjustments necessary to achieve the final match. The digital files, Kodak Approval proofs and films reproduced by this method were sent back to RIT to generate 3M Matchprint III proofs on commercial stock.

3) The original art was photographed by this researcher with the Dicomed digital camera system, creating the RGB files to be used for testing.

4) The digital files and original art was sent to Fidelity Software Imaging in Columbus, Georgia. From the RGB files, Fred Morgan, president of FSI performed the RGB to CMYK conversion with Kolorest, their separation software application. The separation process was repeated until the best match to the original art was achieved with their standard reproduction procedures. The digital files and 3M Matchprint III proofs were sent back to RIT. From their files, films were generated on the Agfa Selectset 5000 and proofs were generated on RIT's 3M Matchprint III proofing system on commercial stock. Due to the shortness of time, FSI was unable to complete the reproductions. For this reason they could not be included in the analysis of this thesis. Their information based on one of the originals can be found in Appendix B, pages 74 through 78.

5) The digital files and original art was sent to Stevenson Photo Color in Cincinnati, Ohio. From the RGB files, Bill Orr supervised the RGB to CMYK conversion with Color Access and Adobe Photoshop. The separation process was repeated until the best match to the original was achieved based on their standard reproduction procedures. Individual specification sheets for each image recorded all adjustments necessary to achieve the final match. The Kodak Approval Proofs and digital files were sent back to RIT. This researcher generated films from the digital files on the Agfa Selectset 5000. Proofs were made with RIT's 3M Matchprint III proofing system.

6) The author produced a third set of reproductions from the digital files using Color Synergy. The separations generated were not used in the testing procedures. The separations generated by this researcher were only to gain the experience and understanding of the reproduction process for facsimile art reproductions. Films were generated on an Agfa SelectSet 5000. The films were proofed with RIT's 3M Matchprint III proofing system on commercial stock.

Evaluation of the Art Reproductions

1) Each observer was required to take the Farnsworth-Munsell 100-Hue test to evaluate their ability to accurately differentiate and discriminate color. All observers passed the test with superior or above average scores.

2) A record was kept of all observer information such as name, age, background and score.

3) All observations were made under standard viewing conditions. They evaluated each original to the reproductions by a standard paired comparison testing procedure. One original was compared to the high-end and digital camera reproductions. The comparison was between the high-end reproduction and Stevenson Photo Color reproduction. The observer was forced to choose one method in favor over the other in regards to five specific parameters. The reproductions were labeled reproduction A and B to con-

ceal the reproduction method used. The reproductions were randomly labeled from each observation to eliminate any observation preferences.

4) Each observer was given a questionnaire with the same questions for each of the five pieces of original art. The parameters were based on evaluating reproductions of the high-end and digital camera system to the original in relation to tone reproduction, gray balance, detail, sharpness and color.

5) Observers were also asked to take all the parameters into consideration and evaluate how well the reproduction matched the original on a scale of one to ten. A rating of ten indicated an exact match in all five categories.

6) Analysis of the data and results were based on three standard testing procedures. The first was a colorimetric test to determine color difference of the original to the reproduction. The second was a paired comparison test forcing a favored method based on five separate specifications. The third was a scaling ratio response with consideration to all five parameters.

Equipment used at Litho Inc.

- Crosfield Drum Scanner
- Scitex Digital Imaging Station
- Scitex Dolev RIP
- Kodak Approval Proofing System

Equipment used at FSI

- Macintosh Quadra 9500 Computer
- Kolorest Color Separation Software
- Linotronic L300 RIP
- 3M Matchprint III proofing system

Equipment used at Stevenson Photo Color

- Macintosh Power PC 8110
- Color Access 1.4.5 Color Separation Software
- Kodak Approval Proofing System

Equipment used at RIT

- Dicomed Digital Camera System
- Broncolor HMI Lighting
- Agfa SelectSet 5000
- 3M Matchprint III proofing system
- X-Rite 948 colorimeter
- Munsell 100 color hue test

Chapter Seven

Results

At the beginning of this experiment three vendors had volunteered their expertise. Litho Inc. in Minnesota performed the high-end reproductions. Stevenson Photo Color in Ohio and Fidelity Software Imaging of Georgia were to perform the CMYK desktop separations from the artwork captured with the digital camera system. Both companies were to perform the same task using different desktop color separation software.

Due to time restraints Fidelity Software Imaging was able to separate only one of the five original pieces of artwork. Unfortunately, the results comparing the two desktop separation procedures are inconclusive. FSI's results for the reproduction of the oil artwork can be found in appendix B.

Three separate tests were performed to thoroughly analyze how well reproductions generated by a digital camera system compared to those reproduced by the industry excepted high-end scanning system. (One) Colorimetric measurements compared the color values of the original against reproductions of each modality. (Two) A subjective paired comparison test evaluated five separate parameters comparing both reproduction methods to the original. (Three) A second subjective test rated both reproduction methods against the original on a scale of one to ten to determine how closely the reproduction matched the original.

A total of 39 observers with experience in the reproduction process were qualified by a pre-test of the Farnsworth-Munsell 100 color hue test. All observers tested had superior to high color discrimination capabilities.

Colorimetric Measurements

The colorimetric measurements were measured with an X-rite 948 with a D50 light source at a 2° observer. A ΔE of 2 is considered a just noticeable difference and very acceptable in the graphic arts. A ΔE between 4 and 6 would also be acceptable but not as desirable. Anything above a 9 would be a substantial difference. The ΔE values below represent the difference in the colors of the original to the colors of the reproduction method. Templates were made from the original for each of the five original art pieces to ensure precise and accurate points of measurement.

Average ΔE Values

Water Color	High-end Reproduction	Digital Camera Reproduction
Point 1	3.635932	4.1
Point2	4.431704	12.5511
Point 3	3.31059	10.80093
Avg ΔE	3.792742	9.150674

Acrylic	High-end Reproduction	Digital Camera Reproduction
Point 1	8.552193	2.580698
Point2	7.675285	6.822023
Point 3	5.768882	7.481978
Point 4	6.316645	4.779121
AvgΔE	7.078251	5.415955

Oil Crayon	High-end Reproduction	Digital Camera Reproduction
Point 1	14.21443	10.23035
Point2	14.81249	10.42785
Point 3	12.30325	11.00772
AvgΔE	13.77673	10.55531

Chalk	High-end Reproduction	Digital Camera Reproduction
Point 1	5.81377	3.595831
Point2	2.172556	1.568439
Point 3	4.259108	4.73392
AvgΔE	4.08180	3.2994

Oil	High-end Reproduction	Digital Camera Reproduction
Point 1	14.21443	10.23035
Point2	7.04557	3.74967
Point 3	4.311621	2.23159
AvgΔE	6.565417	2.644393

Paired Comparison

Each observer had to choose which reproduction better matched the original in terms of tone reproduction, gray balance, color, detail and sharpness. For a two tailed test at a 5% confidence level, 27 of the 39 observers had to choose one in favor of the other in order for a significant difference to occur.

Water Color	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	33	6	Yes
Gray Balance	30	9	Yes
Color	32	7	Yes
Detail	27	12	Yes
Sharpness	22	17	No

Acrylic	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	16	23	No
Gray Balance	13	26	No
Color	15	24	No
Detail	18	21	No
Sharpness	16	23	No

Oil Crayon	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	24	15	No
Gray Balance	30	9	Yes
Color	32	7	Yes
Detail	29	10	Yes
Sharpness	29	10	Yes

Chalk	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	9	30	Yes
Gray Balance	13	26	No
Color	8	31	Yes
Detail	18	21	No
Sharpness	22	17	No

Oil	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	25	14	No
Gray Balance	25	14	No
Color	30	9	Yes
Detail	17	22	No
Sharpness	22	17	No

Rating Scale

38 of the 39 observers rated on a scale of 1 to 10 how well the reproduction matched the original with consideration to tone reproduction, gray balance, color, detail and sharpness. A rating of 10 was a perfect match to the original in all aspects. A rating of 1 meant the reproduction did not come close to matching the original in all of the aspects. The results were analyzed by a two tailed t-test at a 95% confidence level. A value of + or - 1.98 is required for a significant difference to occur between the two reproduction methods.

Water Color	High-end Reproduction	Digital Camera Reproduction	
Mean	7.789	6.053	
Variance	1.900	5.024	
Standard deviation	1.379	2.241	
STD err of the mean	.224	.364	
STD err of the diff b/t the means			.427
Degrees of Freedom			74
t=			4.069

Significant difference in favor of High-end

Acrylic	High-end Reproduction	Digital Camera Reproduction	
Mean	6.053	6.184	
Variance	3.619	2.965	
Standard deviation	1.902	1.722	
STD err of the mean	.309	.279	
STD err of the diff b/t the means			.416
Degrees of Freedom			74
t=			-.316

No significant difference

Oil Crayon	High-end Reproduction	Digital Camera Reproduction	
Mean	7.5	6.079	
Variance	1.878	3.588	
Standard deviation	1.371	1.894	
STD err of the mean	.222	.307	
STD err of the diff b/t the means			.379
Degrees of Freedom			74
t=			3.747

Significant difference in favor of High-end

Chalk	High-end Reproduction	Digital Camera Reproduction	
Mean	6.44	7.908	
Variance	3.443	2.736	
Standard deviation	1.856	1.542	
STD err of the mean	.307	.250	
STD err of the diff b/t the means			.391
Degrees of Freedom			74
t=			-3.732

Significant difference in favor of Digital Camera

Oil	High-end Reproduction	Digital Camera Reproduction	
Mean	6.868	6.023	
Variance	2.388	5.024	
Standard deviation	1.545	2.241	
STD err of the mean	.251	.364	
STD err of the diff b/t the means			.364
Degrees of Freedom			74
t=			1.847

No significant difference

Chapter Eight

Summary and Conclusions

The hypothesis in chapter five states; the Dicomed digital camera system when combined with desktop color separation software, can produce a facsimile art reproduction in terms of color, tone reproduction, gray balance and detail. A second hypothesis states; the Dicomed digital camera system when combined with desktop color separation software, can produce an art reproduction of the same quality level as art reproduced from a high-end color scanner in terms of tone reproduction, gray balance, color, sharpness and detail.

Three separate tests were administered to prove the hypothesis. It would be unfair to group all three tests together since they all have different criteria to prove the hypothesis. To do so would be comparing apples and oranges. However, it's useful to compare them together as a whole in order to analyze any similarities or differences in the results.

Colorimetric Measurements

Avg ΔE	High-end Reproduction	Digital Camera Reproduction
Water Color	3.79274	9.150674
Acrylic	7.078251	5.415955
Oil Crayon	13.77673	10.55531
Chalk	4.08180	3.2994
Oil/Stevenson	6.565417	2.644393

In the graphic arts industry a ΔE value below 6 would be acceptable. The high-end system for the water color art work showed a significantly lower average ΔE value of 3.70372. The digital camera system's average ΔE of 9.150674 falls out of the acceptable range. For this original, hypothesis II is rejected.

The average ΔE values for the acrylic reproduction showed an average of 5.415955 for the digital camera system; while the high-end averaged a ΔE of 7.078251 which falls out of the acceptable range. In this case, although the high-end system is close to an acceptable ΔE value, hypothesis II is accepted for this original in producing color equal to and better than the high-end color scanner.

The average ΔE values for both the high-end color scanner and the digital camera system significantly fall out of the range of acceptability in regards to the oil crayon. Both fail to reproduce facsimile artwork in terms of color. However, the digital camera system reproduced the colors at a lower ΔE value when compared to the high-end color scanner. For this type of an orig-

inal neither reproduction method had acceptable ΔE values. For this original, hypothesis II is accepted because the ΔE value is lower than the high-end

An acceptable range for the chalk reproduction showed the average ΔE values for both the digital camera system and the high-end color scanner. The digital camera system does have a lower average ΔE value of 3.2994. Proving for this original, the digital camera system can reproduce artwork in terms of color equal in quality compared to the high-end color scanner. The results prove that hypothesis II is accepted.

The results of the oil artwork indicate acceptable average ΔE values for the desktop separation system. The high-end system falls just outside of the acceptable difference at an average ΔE of 6.565417. In most cases, this would be considered acceptable for an average ΔE value. Hypothesis II is accepted for this original.

Overall, this test shows colorimetrically the digital camera system had average ΔE values lower than the high-end scanning system for 4 of the 5 reproductions. This shows that the digital camera system, when combined with desktop software, can reproduce art at the same quality level and in some cases better than art reproduced from a high-end scanner in terms of color. Therefore, hypothesis II is accepted.

Paired Comparison

In practice, reproducing artwork is not based on colorimetric measurements. There are many more factors that are attributed to the high cost of producing a facsimile reproduction. Not to mention the fact that people do not judge art reproductions by numeric values. Human perception is the most scientific analysis of how well the reproduction method reproduced the original artwork.

Unfortunately, human perception is also varied depending on the observer's physical, environmental and emotional conditions. Every attempt was made to maintain the controllable factors in order keep the settings consistent from observer to observer. A paired comparison test was administered to force the observer to choose which reproduction method matched closest to the original in terms of tone reproduction, gray balance, color, detail and sharpness.

This does not conclude (hypothesis I) the overall quality an acceptable or exact match to the original in terms of tone reproduction, gray balance, color, detail and sharpness. It is only forcing them to choose the closer match to the original out of the two reproductions. A paired comparison test does show a significant difference of the two methods. 27 of the 39 observers for a two tailed test at a 5% confidence level had to choose one in favor over the other in order for a significant difference to occur. A 5% level difference between the two averages of two experimental treatments suggests that the finding of no difference would be unlikely; it should happen no

more often than one in twenty repetitions. However, finding a significant difference as large or at the same level of significance whenever the experiment is replicated.[1] It means only that one should expect to find a difference greater than zero and in the same direction as before.

If no significant difference occurred both reproduction methods reproduced the art work equally. Statistically it is hard to analyze all five criteria as a whole because they are all very different. Even though they effect one another, the goal was to isolate a specific criteria and judge the reproduction solely on that criteria. An assumption might be if a reproduction has a significant difference for a majority of the criteria, that reproduction method would be a better match.

Significant Difference

	Tone reproductions	Gray balance	Color	Detail	Sharpness
Water Color	high-end	high-end	high-end	high-end	
Acrylic					
Oil Crayon		high-end	high-end	high-end	high-end
Chalk	digital camera		digital camera		
Oil			high-end		

There was a significant difference in tone reproduction in favor of the high-end color scanner for the water color. Alternatively, a significant difference was in favor of the digital camera system for the chalk reproduction. No significant differences were found for the remaining reproductions. In terms of tone reproduction, the digital camera system when combined with desktop

color separation software, can produce an art reproduction of the same quality level as art reproduced from a high-end color scanner.

For gray balance and detail, no significant difference was found for 3 of the 5 reproductions. 2 of the 5 reproductions did have a significant difference in favor of the high-end scanner. This does not prove the digital camera system when combined with desktop separation software is incapable of achieving gray balance or detail. A majority of the reproductions showed no significant difference in both these areas. This concludes overall the acceptance of hypothesis II. The digital camera system when combined with desktop color separation software can produce an art reproduction of the same quality level as art reproduced from a high-end color scanner in terms of gray balance and detail.

A similar situation occurred for sharpness. 4 of 5 reproductions showed no significant difference with 1 of the 5 art reproductions showing a significant difference in favor of the high-end. Again a majority of the reproductions showed no significant difference, proving the digital camera system when combined with desktop color separation software can produce an art reproduction of the same quality level as art reproduced from a high-end color scanner in terms of sharpness.

Color is the only criteria that has the greatest amount of significant differences overall. Although the testing environment was controlled in this research, color perception can differ from person to person based on several

variables such as prior experience, physical and emotional state as well as the nature of the object being viewed.

The colorimetric measurement readings indicated the digital camera system had lower ΔE values compared to the values of the high-end color scanning system. One would assume similar results with a subjective evaluation. Analyzing the color data from the observer's responses showed different results. No significant difference was found for the acrylic reproduction. The water color and the oil crayon reproductions showed a significant difference in favor of the high-end scanner. The chalk reproduction showed a significant difference in favor of the digital camera system.

The oil reproduction showed a significant difference in favor of the high-end scanner when compared with the separation method used by Stevenson Photo Color. In terms of color, the high-end system showed a significant difference for 3 of the 5 reproductions. The digital camera showed a significant difference for 1 of the 5 reproductions. The remaining reproduction showed no significant difference. In terms of color it can be concluded that the the digital camera system when combined with desktop color separation software, cannot produce an art reproduction of the same quality level as art reproduced from a high-end color scanner. However, this researcher found that there was no significant difference between the oil reproduction produced by FSI (on the desktop) versus the high-end reproduction. This finding challenges the above statement, refer to appendix B for these results. When all five parameters are viewed collectively for an original, it shows the

observers preferred the high-end over the digital camera system for the water color and the oil crayon. The digital camera system had a stronger advantage for the chalk original. The remaining two originals had no strong significant difference between either modality. Since neither reproduction was favored, this would indicate the acceptance of hypothesis II.

Rating Scale

A rating scale of one to ten was to see how closely the reproductions match the original. A rating of ten would indicate the reproduction matches the original in terms of tone reproduction, gray balance, color, sharpness and detail. A rating of one would indicate the reproduction was the furthest from an exact match in relation to tone reproduction, gray balance, color, sharpness and detail. For a two tailed test at a 95% confidence level a value of + or -1.98 is required for a significant difference.

t-test	Mean		t=	significant difference
	High-end	Digital camera		
Water Color	7.789	6.053	4.069	high-end
Acrylic	6.053	6.184	-.0316	
Oil Crayon	7.500	6.079	3.747	high-end
Chalk	6.447	7.908	-3.732	digital camera
Oil	6.868	6.053	1.847	

This test showed similar preference to the same reproductions as the paired comparison test. There was a significant difference for the water color and the oil crayon indicating a closer match to the original was in favor of the high-end reproduction method. A closer match with the chalk showed a sig-

nificant difference in favor of the digital camera system. The remaining reproductions showed no significant difference indicating equal results. Three of the five reproductions were equal or in favor of the digital camera system. This proves hypothesis II; which states the digital camera system when combined with desktop color separation software, can produce an art reproduction of the same quality level as art reproduced from a high-end color scanner. The average mean for both systems was no less than 6 and no greater than 7.9. This indicates that neither system was capable of reproducing a "true facsimile reproduction". An exact match would need to have an average mean of above 9.

Conclusions

Observing all three test results, one can conclude the failure of the first hypothesis; which stated, the Dicomed digital camera system when combined with desktop color separation software, can produce a facsimile art reproduction in terms of color, tone reproduction, gray balance and detail. As stated previously, the traditional method known as the high-end color scanning system also failed to produce a facsimile reproduction. This is not surprising because of the difficulty in reproducing artwork. The results do conclude the success of the second hypothesis; which states the Dicomed digital camera system when combined with desktop color separation software, can produce an art reproduction of the same quality level as art reproduced from a high-end color scanner in terms of tone reproduction, gray balance, color, sharpness and detail.

It cannot be assumed that the high-end system or the digital camera system is capable of achieving better results for certain types of artwork. For example, the water color and the oil crayon showed an observers preference to the high-end system and a strong preference in regards to the chalk original for the digital camera system. This may indicate the individual, physical and aesthetic properties contained in the original had a strong influence in observers response.

The results do conclude both systems are capable of reproducing artwork that is extremely close in resemblance to the original art. Overall, there was very little appreciable differences between either modality. For high quality reproductions one must factor the quality of the input device combined with the skill and experience of the separator. The results prove the digital camera system can provide industry with the tools to produce high quality art reproductions having a great impact on how art is reproduced in the future.

Using a digital camera system for the reproduction process will provide many advantages over the high-end system in situations which require the safe handling and preservation of valuable and delicate art. Reproductions can be made directly from the original art which reduces the loss of detail and color accuracy. Reproduction of large art and delicate art can be captured directly from the original without going to a second generation. Periodically recreating conversion transparencies of artwork for archiving and reproduction purposes is eliminated. Cost saving can be gained from the elimination of

film and processing. This also increases productivity because the time spent waiting for the film to be processed is gone. Changes in exposure can be made automatically. Files are automatically created and ready for use which saves the cost of relying on outside sources for the scanning and separation process.

Reproducing artwork is an extremely challenging and difficult task. The artist's pallet is extremely hard to reproduce with the same aesthetic feeling that is contained in the original. From an observational opinion, a statistical analysis based on numbers which compare both methods does not do either system any justice. In some cases observers commented that neither reproduction came close to matching the original. In other cases observers commented on how difficult a decision it was because both processes were so close to the original. This could be an indication that when judging artwork for facsimile reproductions, the characteristics such as skin tones, etc. contained in the original have a strong influence in the response.

For the practicality of this test, all possible input variables had to be eliminated showing a one to one reproduction. This included both systems working directly from the original. It was necessary for the artwork to be flexible enough to wrap around the drum of the high-end scanner. Artwork is vulnerable and susceptible to damage. Extreme caution is always taken to preserve the original. In reality, when art is reproduced on a high-end system a copy transparency is created in order to preserve the original. The copy transparency would introduce a color bias based on the characteristic of the film emulsions making a color match extremely difficult. Plus, the reproduc-

tion would be scanned from a second generation causing a loss in resolution. This variable is a common practice in industry for the high-end scanning system. One can assume greater results for the digital camera system since it is has the advantage of working directly from the original.

Recommendations for Further Investigation

For this project, time did not permit extensive research in a cost analysis between the two systems. A comparison of production time and cost may provide industry with further information. Outside of this project technology is rapidly advancing for all digital camera systems. Further investigation in any area pertaining to digital camera technology would be recommended. As the months pass, digital camera systems will be obsolete and new systems with advanced capturing and output capabilities will be arising continuing to erode the use of film for all reproduction purposes.

Chapter Eight Endnotes

[1] American Society for Testing and Materials. *Manual on Sensory Testing Methods.* Baltimore, MD:1973.

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Appendix A

Appendix A

Testing Procedure Specifications

Method Used

Sample material to be reproduced was collected from various artists. Test samples represent a variety of media such as oil and acrylic paintings, watercolors and pastels. These samples are of appropriate size and media to ensure that both the high-end scanning system and the Dicomed digital camera system have equal ability to reproduce the tested material.

Scanning the originals on a high-end scanning system was the first method chosen to achieve facsimile art reproductions. This current industry standard is a method known to achieve facsimile reproductions. This method acted as the control for the testing procedure. A Dicomed digital camera system combined with desktop color separation software was used as the testing variable by analyzing its ability to achieve facsimile reproductions in comparison to current methods used in the reproduction industry.

The original art samples underwent both reproduction methods. To be an accurate test of each system, three companies specializing in color separation from original art were asked to produce a facsimile reproduction from the same originals. The high-end scanner separations were prepared by Litho Inc. in Minnesota, a company known for high quality art reproductions.

The desktop system relies heavily on the RGB to CMYK software for the separation in order to achieve accurate color. This was an extremely important issue for this thesis research. In order to test a variety of separation software available, two skilled companies worked with their choice of separation software to perform the RGB to CMYK separations. Fidelity Software Imaging of Georgia used Kolorest, created by FSI as their color separation software to convert the RGB files created with the Dicomed digital camera system into CMYK separations. Stevenson Photo Color in Cincinnati, Ohio used Color Access to perform the RGB to CMYK separations. This researcher produced a third set of separations using Color Synergy on the desktop system. This added procedure was not used when judging the hypothesis since the experience and skill is not equivalent to the high end procedure. It was performed to give this researcher a clear understanding of the limits of this technique as well as the difficulty in producing a facsimile art reproduction. Each operation performed was worked from the same originals to exclude any variables.

To eliminate any proofing variability, all films received were proofed on commercial stock with the 3M Matchprint III proofing system at RIT. Prior to the start of the test, a test page from RIT's 3M Matchprint III proofing system was generated to measure the hue error of the ink on commercial stock ordered for this test. The results were sent to Litho Inc., FSI and Stevenson to calibrate their proofing systems with RIT's Matchprint III proofing system. This was to ensure consistent results and eliminate variables in proofing.

Litho, Inc., is a color printer in Minnesota experienced in high quality facsimile art reproductions using a high-end system and digital imaging work stations. Five originals were reproduced by them with instructions to produce the best possible fac-

simile reproductions capable with their standard procedures. This process was supervised by Kimberly Pietrzak, a specialist in the reproduction process at Litho, Inc.

The control method that Litho Inc. followed was to wrap the originals around the drum of a Crosfield scanner. Any adjustments, such as highlight placement, midtone placement, tone compression and color correction were recorded. Any additional adjustments made for each separation were also recorded. The CMYK digital files were downloaded into a Scitex digital imaging station where further color corrections were made to better match the originals. The files were proofed on a Kodak Approval proofing system. From the first generation proofs, further alterations were made until the best facsimile reproduction was achieved. An individual specification sheet for each image was supplied for recording all adjustments necessary to achieve the final match. Films from these files were generated on a Scitex Dolev RIP at 175 lpi. The digital files, Kodak Approval proofs and films were sent back to RIT to generate 3M Matchprint III proofs. To eliminate any proofing variability, all films were proofed on commercial stock with the 3M Matchprint III proofing system. Control targets were included to verify accuracy of the proofs.

The Dicomed digital camera system was the second method tested. The original art was photographed by this researcher using the Dicomed digital camera system along with the use of two Broncolor HMI lighting units. Since this method relied heavily on the desktop system, color separation software was required to prepare the files for the printing process by converting the original RGB files into CMYK. Once captured at a resolution of 300 spi, each RGB digital file generated from the Dicomed digital camera system was sent to Fred Morgan, president of FSI and Bill

Orr at Stevenson Photo Color to perform the RGB to CMYK separations. Fidelity Software Imaging is a software company in Columbus Georgia, skilled in conversion technology. Stevenson Photo Color is a printing company that specializes in producing facsimile reproductions. The procedure FSI and Stevenson Photo Color followed was similar to the high-end method.

Separations at FSI were produced with Kolorest color separation software on a Macintosh Quadra 9500 computer containing 24 megabytes of RAM. FSI was able to reproduce only 1 of the 5 originals, therefore their results could not be used conclusively. The results for the oil original were included only for the sole comparison of one reproduction using a second desktop separation procedure. Results can be found in Appendix B, pages 75 through 78.

Separations at Stevenson Photo Color were separated with Color Access on a Macintosh Power PC 8110 computer containing 40 megabytes of RAM. From the RGB files, separations with Color Access software were adjusted in terms of detail enhancement, color correction, tone reproduction, and gray balance. Each of these characteristics was altered specifically for each file to insure the best possible reproduction. All adjustments were recorded. Proofs were generated with a Kodak Approval digital proofing system. From the first generation of proofs, further adjustments were made until the best match to the original art was achieved with their standard reproduction procedures. The digital files and proofs were sent back to the researcher at RIT. This researcher then generated films from the digital files on the Agfa SelectSet 5000. All proofs were made on RIT's 3M matchprint III proofing system.

This researcher produced a third set of separations with the RGB digital files on the desktop with the use of Color Synergy. Films were generated with an Agfa SelectSet 5000 from the digital files. The films were proofed at RIT with the 3M Matchprint III proofing system on commercial stock.

To test the hypothesis, proofs from the high-end and digital camera systems were evaluated visually by a sample size of 38 people from various backgrounds. This included subjects with experience in printing, design and art. Prior to judging, each person was tested with the Farnsworth-Munsell 100-hue test, to ensure proper color vision and discrimination. After passing the test, each observer viewed the unmarked proofs under standard viewing conditions at RIT. In order to limit the bias of the observer, the proofs were labeled reproduction A and B. The labels were altered randomly from one observer to the next to eliminate any observer preferences. The size of the original and the size of the reproduction were equal to eliminate any variables associated with size difference.

Viewers were required to answer specific questions in a survey form comparing the tone reproduction, gray balance, color, detail and sharpness of original to the sets of unmarked proofs against the original. A glossary of terms was provided to clear any uncertainties to the viewer.

Colorimetric measurements, a paired comparison and a rating scale were analyzed to determine the validity of the hypothesis 1 and 2.

Appendix B

Appendix B

Fidelity Software Imaging Results

Average ΔE Values

Oil/Stevenson	High-end Reproduction	Digital Camera Reproduction
Point 1	14.21443	10.23035
Point2	7.04557	3.74967
Point 3	4.311621	2.23159
AvgΔE	6.565417	2.644393

Oil/FSI	High-end Reproduction	Digital Camera Reproduction
Point 1	14.21443	10.23035
Point2	7.04557	3.74967
Point 3	4.311621	2.23159
AvgΔE	6.565417	2.644393

Paired Comparison

Oil/Stevenson	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	25	14	No
Gray Balance	25	14	No
Color	30	9	Yes
Detail	17	22	No
Sharpness	22	17	No

Oil/FSI	High-end Reproduction	Digital Camera Reproduction	Significant difference
Tone Reproduction	17	19	No
Gray Balance	19	19	No
Color	21	17	No
Detail	13	25	No
Sharpness	14	24	No

Rating Scale

Oil/Stevenson	High-end Reproduction	Digital Camera Reproduction	
Mean	6.868	6.023	
Variance	2.388	5.024	
Standard deviation	1.545	2.241	
STD err of the mean	.251	.364	
STD err of the diff b/t the means			.364
Degrees of Freedom			74
t=			1.847

No significant difference

Oil/FSI	High-end Reproduction	Digital Camera Reproduction	
Mean	7.079	7.158	
Variance	2.021	2.785	
Standard deviation	.231	2.241	
STD err of the mean	.251	.271	
STD err of the diff b/t the means			.356
Degrees of Freedom			74
t=			-.222

No significant difference

Analysis of Results

The oil color original was the only original to be reproduced by FSI with their desktop separation software Kolorest. The three tests were performed for this reproduction to observe any differences between the two desktop separations for this original. The above data shows FSI's results along with Stevenson's results when both are compared to the results from the high-end scanning system. All reproductions were judged on how well the reproduction matched the original.

Overall a majority of the test results concluded that both desktop reproduction systems were equal or had no significant difference when compared to the high-end system. Colorimetrically both systems had acceptable ΔE values. Both systems also had lower values compared to the high-end scanning system. The paired comparison test showed only one major difference in regards to color. Stevenson's reproduction showed a significant difference in favor of the high-end system while FSI's reproduction showed no significant difference. This may indicate a variable in the skill of the operator for this original. The last test showed no significant difference between both desktop systems when compared the the reproduction from the high-end scanning system.

Appendix C

Appendix C

Raw Data Tables

Water Color 1

	original	Litho
L*	30.6	29.8
a*	-3.2	-1.9
b*	-5.9	-2.6
ΔE		3.635932

Water Color 2

	original	Litho
L*	81.2	77.4
a*	13.2	15
b*	35.1	36.5
ΔE		4.431704

Water Color 3

	original	Litho
L*	77.1	74.7
a*	17.4	19.2
b*	36.7	38.1
ΔE		3.310589

Water Color 1

	original	Stevenson
L*	30.6	33
a*	-3.2	-0.9
b*	-5.9	-3.5
ΔE		4.1000

Water Color 2

	original	Stevenson
L*	81.2	74.2
a*	13.2	9.4
b*	35.1	25.4
ΔE		12.5511

Water Color 3

	original	Stevenson
L*	77.1	71.2
a*	17.4	13.8
b*	36.7	28.4
ΔE		10.80093

Acrylic 1

	original	Litho
L*	67.2	61.9
a*	14.7	18.4
b*	32.2	26.6
ΔE		8.552193

Acrylic 2

	original	Litho
L*	80.5	75.6
a*	7.4	12.3
b*	35.5	38.8
ΔE		7.675285

Acrylic 3

	original	Litho
L*	32.4	35.6
a*	-11	-11
b*	-4.6	0.2
ΔE		5.768882

Acrylic 4

	original	Litho
L*	65.4	59.6
a*	-10.7	-8.2
b*	-21	-21.1
ΔE		6.316645

Acrylic 1

	original	Stevenson
L*	67.2	65.1
a*	14.7	13.5
b*	32.2	33.1
ΔE		2.580698

Acrylic 2

	original	Stevenson
L*	80.5	76.3
a*	7.4	2.1
b*	35.5	34.6
ΔE		6.822023

Acrylic 3

	original	Stevenson
L*	32.4	30.1
a*	-11	-4.8
b*	-4.6	-1.1
ΔE		7.481978

Acrylic 4

	original	Stevenson
L*	65.4	61.2
a*	-10.7	-9.3
b*	-21	-22.8
ΔE		4.779121

Table 1C: ΔE Values

Oil Crayon 1

	original	Litho
L*	65.4	59.3
a*	-45.2	-44.2
b*	11.2	24
ΔE		14.21443

Oil Crayon 2

	original	Litho
L*	52.2	49.4
a*	55.3	44.2
b*	44.8	35.4
ΔE		14.81249

Oil Crayon 3

	original	Litho
L*	47.5	48.1
a*	52.6	45.6
b*	14.9	25
ΔE		12.30325

Oil Crayon 1

	original	Stevenson
L*	65.4	62.3
a*	-45.2	-36.5
b*	11.2	6.8
ΔE		10.23035

Oil Crayon 2

	original	Stevenson
L*	52.2	51.9
a*	55.3	47.4
b*	44.8	38
ΔE		10.42785

Oil Crayon 3

	original	Stevenson
L*	47.5	49.1
a*	52.6	43.2
b*	14.9	20.4
ΔE		11.00772

Chalk 1

	original	Litho
L*	35.8	35.4
a*	6.9	10.9
b*	-6	-10.2
ΔE		5.813777

Chalk 2

	original	Litho
L*	27.5	25.5
a*	0.1	0.7
b*	-0.4	-1
ΔE		2.172556

Chalk 3

	original	Litho
L*	50.5	52.8
a*	7.3	10.6
b*	6.5	7.9
ΔE		4.259108

Chalk 1

	original	Stevenson
L*	35.8	34.7
a*	6.9	6.5
b*	-6	-9.4
ΔE		3.595831

Chalk 2

	original	Stevenson
L*	27.5	26.4
a*	0.1	-0.1
b*	-0.4	-1.5
ΔE		1.568439

Chalk 3

	original	Stevenson
L*	50.5	48
a*	7.3	7.7
b*	6.5	2.5
ΔE		4.73392

Table 2C: ΔE Values

Oil 1

	original	Litho
L*	50.1	43.3
a*	10.8	9.7
b*	-16.3	-11.6
ΔE		8.339065

Oil 2

	original	Litho
L*	42.1	37.9
a*	29.5	23.9
b*	11.1	10.3
ΔE		7.045566

Oil 3

	original	Litho
L*	28.7	25
a*	6.6	5.9
b*	-2.3	-0.2
ΔE		4.311612

Oil 1

	original	Stevenson
L*	50.1	49.7
a*	10.8	12.2
b*	-16.3	-17.6
ΔE		1.951922

Oil 2

	original	Stevenson
L*	42.1	40
a*	29.5	26.9
b*	11.1	9.4
ΔE		3.749667

Oil 3

	original	Stevenson
L*	28.7	27.1
a*	6.6	7.7
b*	-2.3	-3.4
ΔE		2.231591

Oil 1

	original	FS1
L*	50.1	51.8
a*	10.8	10.1
b*	-16.3	-11.7
ΔE		4.953786

Oil 2

	original	FS1
L*	42.1	39
a*	29.5	23.5
b*	11.1	7.3
ΔE		7.749194

Oil 3

	original	FS1
L*	28.7	28.9
a*	6.6	5.8
b*	-2.3	-2.1
ΔE		0.848528

Table 3C: ΔE Values

Water Color

	Litho	Stevenson
1	3.635932	4.1
2	4.431704	12.5511
3	3.310589	10.80093
Avg ΔE	3.792742	9.150674

Acrylic

	Litho	Stevenson
1	8.552193	2.580698
2	7.675285	6.822023
3	5.768882	7.481978
4	6.316645	4.779121
Avg ΔE	7.078251	5.415955

Oil Crayon

	Litho	Stevenson
1	14.21443	10.23035
2	14.81249	10.42785
3	12.30325	11.00772
Avg ΔE	13.77673	10.55531

Chalk

	Litho	Stevenson
1	5.813777	3.595831
2	2.172556	1.568439
3	4.259108	4.73392
Avg ΔE	4.081814	3.299397

Oil

	Litho	Stevenson	FSI
1	8.33906	1.95192	4.95379
2	7.04557	3.74967	7.74919
3	4.311621	2.23159	0.84853
Avg ΔE	6.565417	2.644393	4.51717

Table 4C: Average ΔE Values

Water Color

# of Observers	Highend Reproductions	Digital Camera Separations
1	7	7
2	9	8
3	8	6
4	9	6
5	9	7
6	6	7
7	9	6
8	8	6
9	9	8
10	3	7
11	9	6
12	8	9
13	7	7
14	5	4
15	8	4
16	9	6
17	9	4
18	9	7
19	5	7
20	9	6
21	9	4
22	8	4
23	8	4
24	8	4
25	8	5
26	7	5
27	6	7
28	7	5
29	8	7
30	8	4
31	9	9
32	9	8
33	7	6
34	8	5
35	8	6
36	7	5
37	7	7
38	9	7

Total	296	230
Mean	7.79	6.05
Variance	1.90	5.02
Std DEV	1.38	2.24
STD ERR of Mean	0.224	0.364
STD ERR of Diff B/T The Means	0.43	
DG of Freedom	74	
T=	4.07	

Table 5C: Visual Analysis

Acrylic

# of Observers	Highend Reproductions	Digital Camera Separations
1	6	6
2	4	9
3	4	6
4	7	6
5	5	9
6	8	8
7	7	8
8	3	4
9	7	6
10	4	6
11	10	8
12	8	3
13	3	7
14	7	6
15	5	7
16	8	7
17	6	8
18	7	7
19	5	6
20	9	7
21	7	4
22	6	8
23	2	3
24	3	4
25	7	6
26	6	8
27	8	6
28	8	2
29	7	7
30	8	6
31	6	4
32	5	8
33	5	4
34	5	8
35	8	6
36	8	5
37	4	6
38	4	6
Total	230	235
Mean	6.05	6.18
Variance	3.62	2.97
Std DEV	1.90	1.72
STD ERR of Mean	0.309	0.279
STD ERR of Diff B/T The Means	0.42	
DG of Freedom	74	
T=	-0.32	

Table 7C: Visual Analysis

Oil Crayon

# of Observers	Highend Reproductions	Digital Camera Separations
1	8	5
2	9	3
3	9	9
4	8	6
5	8	3
6	8	8
7	7	7
8	9	8
9	6	8
10	6	5
11	7	9
12	7	4
13	8	3
14	8	5
15	8	6
16	8	7
17	7	8
18	8	5
19	5	3
20	7	8
21	10	4
22	8	6
23	5	8
24	6	3
25	8	6
26	9	7
27	9	8
28	7	5
29	4	7
30	9	7
31	8	7
32	7	4
33	9	9
34	8	6
35	7	5
36	9	8
37	6	4
38	5	7

Total	285	231
Mean	7.50	6.08
Variance	1.88	3.59
Std DEV	1.37	1.89
STD ERR of Mean	0.222	0.307
STD ERR of Diff B/T The Means	0.38	
DG of Freedom	74	
T=	3.75	

Table 8C: Visual Analysis

Chalk

# of Observers	Highend Reproduction	Digital Camera Separation
1	6	9
2	3	8
3	6	8
4	7	9
5	8	9
6	8	10
7	8	9
8	3	9
9	8	8
10	5	7
11	7	10
12	6	7
13	8	4
14	6	9
15	6	8
16	8	9
17	8	8
18	9	6
19	6	8
20	8	9
21	8	7
22	6	8
23	7	4
24	3	7
25	9	6
26	8	9
27	7	9
28	5	7
29	1	10
30	7	9
31	5	9
32	6	8
33	7	5
34	5	9
35	9	5
36	7	8.5
37	4	8
38	7	8
Total	245	301
Mean	6.45	7.91
Variance	3.44	2.74
Std DEV	1.86	1.54
STD ERR of Mean	0.301	0.25
STD ERR of Diff B/T The Means	0.39	
DG of Freedom	74	
T=	-3.73	

Table 9C: Visual Analysis

Oil

# of Observers	Highend Reproduction	Digital Camera Separation
1	5	6
2	7	4
3	8	8
4	6	6
5	8	4
6	9	9
7	8	9
8	6	4
9	8	7
10	5	6
11	6	9
12	6	8
13	5	8
14	5	6
15	9	8
16	7	9
17	8	7
18	8	5
19	6	5
20	8	7
21	8	5
22	8	8
23	4	2
24	4	3
25	7	6
26	5	9
27	9	6
28	6	2
29	10	1
30	5	2
31	8	6
32	7	8
33	5	7
34	6	4
35	8	5
36	7	9
37	7	5
38	9	7
Total	252	223
Mean	6.87	6.05
Variance	2.39	5.02
Std DEV	1.55	2.24
STD ERR of Mean	0.251	0.364
STD ERR of Diff B/T The Means	0.44	
DG of Freedom	74	
T=	1.85	

Table 10C: Visual Analysis

Oil/FSI

# of Observers	Highend Reproductions	Digital Camera Separations
1	6	6
2	4	9
3	7	7
4	7	8
5	8	7
6	9	9
7	8	7
8	9	8
9	6	7
10	6	3
11	7	8
12	9	8
13	9	8
14	4	7
15	8	8
16	7	8
17	6	4
18	8	10
19	6	8
20	7	4
21	7	8
22	5	3
23	7	8
24	8	9
25	6	5
26	7	5
27	6	8
28	9	8
29	8	9
30	7	6
31	7	7
32	6	7
33	9	9
34	8	6
35	7	8
36	8	7
37	4	7
38	9	8
Total	269	272
Mean	7.08	7.16
Variance	2.02	2.79
Std DEV	1.42	1.67
STD ERR of Mean	0.231	0.271
STD ERR of Diff B/T The Means	0.36	
DG of Freedom	74	
T=	-0.22	

Table 11C: Visual Analysis

Visual Analysis Questionnaire

Definitions

Tone Reproduction refers to how accurately the reproduction interprets the tones or tonal distribution of the original. It also refers to the ability to reproduce the general contrast of the original accurately.

Gray balance is obtained when the right combinations of cyan, magenta and yellow dot size are used to reproduce neutral grays. A gray object should be reproduced accurately as a neutral gray. If gray balance is attained, but there is no neutral gray object in the original, the colors should be rendered correctly. Do the colors of the reproduction generally match (green grass, blue sky, red apple) If the colors are significantly off from the original, the gray balance is off.

Color Fidelity refers to how accurate the colors in the reproduction match the color or hue of the original.

Detail refers to the fine lines and intricate textures in the original.

Sharpness refers to how sharp the reproduction appears compared to the original.

Title Of Original Art l

1) Which reproduction best matches the original for correct tone reproduction?

A B

2) Which reproduction best matches the original for correct gray balance?

A B

3) Which reproduction achieved the closest match in color compared to the original?

A B

4) Which reproduction achieved the best match in detail compared to the original?

A B

5) Which reproduction achieved the best match in sharpness compared to the original?

A B

6) How closely was a true facsimile reproduction achieved on a scale of 1 to 10? 10 is an exact match to the original.

Reproduction a	1	2	3	4	5	6	7	8	9	10
Reproduction b	1	2	3	4	5	6	7	8	9	10