Project Introduction[*]

J. Ryan Stinnett
Jennifer Gillenwater

1 Problem Statement

The ability to image sketches hidden by layers of paint is a valuable asset to art purchasers in their attempts to exhaustively examine the works they collect. Art conservators value a painting's underdrawings for two main reasons. The first is that underdrawings can be exploited as an aid in determining whether the painting is an original or a forgery, by comparing the style of the underdrawings to those of an artist's other works. The second is that comparisons between a painting and its own underdrawing can give new insights into an artist's creative process for that work of art. Underdrawing images are best revealed by near infrared (NIR) cameras because all paint pigments, except black, are somewhat transparent in the 900 - 1700 nm range[9]. However, current NIR cameras that are sensitive in this wavelength range are exorbitantly expensive, typically costing around $50,000[8]. This leaves the market of small art museums and individual art collectors unaddressed. We intend to deliver an NIR camera that meets or exceeds key imaging system parameters in this market, such as spectral range, image resolution, capture time, and portability, while also reducing cost below the $5,000 level.

2 Background

Before the 1960s, there was only one way to examine a painting's underdrawing: the layers of paint in front of the underdrawing had to be removed, thereby destroying the painting in the process. This was unacceptable for multiple reasons. Since underdrawings are typically of less interest than the finished painting, removing the layers of paint on top is not justified. Also, many interesting results come from a detailed comparison between the original painting and its underdrawing. This comparison is difficult if the paint layers must be destroyed to access the underdrawing.

J. R. J. van Asperen de Boer was the first to image underdrawings using NIR reflectography in 1968 [11]. Previous attempts had used an NIR camera to passively capture light in that range. However, with passive capture it was difficult to see through pigments such as green, since most of the light collected was in the range of 750 - 900 nm, which is below the range where those colors are transparent. Boer solved this problem by capturing the reflected light from a tungsten lamp that produced radiation of wavelengths up to 2500 nm, giving a much clearer image of the underdrawing. While Boer's design has been improved in numerous ways during the past four decades, it remains fundamental to most techniques for imaging underdrawings nondestructively.

Figure 1 and Figure 2 below are examples of comparisons between original paintings and their underdrawings as captured with a typical modern NIR camera. In Figure 1, the underdrawing shows that the

---

[*]Version 1.1: Apr 29, 2008 5:09 am GMT-5
[†]http://creativecommons.org/licenses/by/2.0/

man in the top hat, the artist's accountant, was initially looking towards the viewer, but later this changed so that he looked away, purportedly because of disagreements between the two men [1]. In Figure 2, a large arrow can be seen on the chest of a horse on the underdrawing of a painting by Laib. This arrow is absent from the overlaid painted image.

Figure 1: Comparison between NIR and visible range images of a Renoir painting [1].
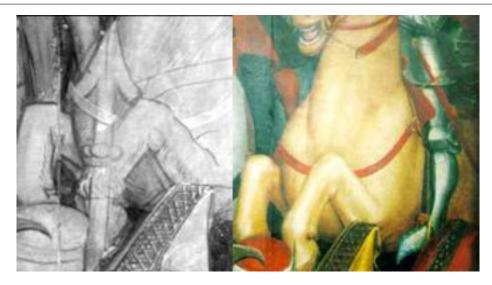

Figure 2: Comparison between NIR and visible range images of a Laib painting [2].

Unfortunately, conventional NIR cameras that cover the spectral range required for a clear image of underdrawings typically cost from $30,000 to $50,000. By reducing the cost of the NIR camera, underdrawings could be examined by a much larger set of universities, museums, and collectors. This opens numerous opportunities to gain deeper insight into both the creative process and the history of artwork.

3 Problem Requirements and Specifications

The spectral range of a camera depends on the type of detectors it employs. Thus, whatever the overall structure of our design, it will have to incorporate a sensor capable of imaging through paint. All pigments except black are somewhat transparent in the 900 - 1700 nm range, which can easily be covered by any NIR detector [9]. Even though our problem probably constrains us to using an NIR detector of some sort, this still leaves us a variety of options. We will want to choose a detector that has minimal cost, in order to keep the final camera price low. We will also want a detector that is appropriately sized so that it can easily be physically integrated into our overall optical system. Additionally, we will need to ensure that any detector we choose is capable of providing the dynamic range required for underdrawing imaging. That is, 256 grey levels should be distinguishable in the image [4].

As Boer found in his original experiments with reflectography, for high-quality underimaging a specialized light source is necessary, to provide coverage of all relevant wavelengths in the NIR range [11]. Our system would also need such a source of radiation. For this source, or sources, 800 W of power is a high enough value to give a good signal-to-noise ratio (SNR) in standard room temperature conditions [7]. Using significantly higher power is not advisable, as most sources will emit a certain portion of their light in the UV and visible ranges, and it will be difficult to filter out all of this. Intense light from these high-energy ranges could damage a painting during imaging.

The image acquisition time when imaging underdrawings is quite flexible. While experience with conventional charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) digital camera technology in the visible range would lead one to expect image acquisition time on the order of μsec, such a short acquisition time is not critical for this application. A relatively small number of images are typically taken with a static target. The resulting images are typically subjected to extensive analysis and comparison with similar images of underdrawings from the same artist. When all of these factors are taken together, a small image acquisition time becomes a nice extra feature when possible, but is not crucial for success in this application domain. Typical systems targeted towards underdrawing imaging take about 15 minutes to acquire and process an image due to the mosaicing system used. For the underdrawing imaging application, the relaxed image acquisition time requirement makes it possible to consider sacrificing low acquisition time for improved image quality, improved image resolution, or reduced camera cost.

Portability is a valuable and highly preferred feature for underdrawing inspection. For cumbersome systems, or systems that are difficult to relocate, artwork can be moved to the location of the camera for inspection. However, this need for transportation puts the original artwork at risk for damage. Since such great care is needed to move the artwork, a portable camera would be a much better solution since it removes this potential hazard. Reducing the risk of damage to the original artwork is critical because, while it is generally possible to replace a broken camera, it is impossible to replace the artwork.

While analyzing underdrawings does not directly mandate a specific image resolution, one must be able to make out the various lines with reasonable clarity in order to derive meaningful results. By image resolution, we mean a pixels / mm specification for the final reconstructed image of the underdrawing. A camera with a low image resolution could be used, but one would need to take many pictures by zooming in on small parts of the target. These pieces would later need to be aligned and stitched together to view the entire underdrawing, a process which is time consuming and could be quite involved for the user. A better approach is to use a camera with a larger image resolution which can capture the entire underdrawing or areas of interest with only one or several pictures. According to our initial research, a system that can provide at least 2 pixels for each mm of target length should be sufficient [10]. We expect to use our design with small to medium paintings, as indicated by the average target size of 0.33 m x 0.33 m. This assumes our system will have a field of view (angular observable range) comparable with the largest artwork size.

4 Existing Technologies

There are a variety of systems that can be used to image underdrawings. Most contain as their central component cameras such as the two listed in the table below.

Five alternatives for the detector component of such cameras were surveyed by Gargano, Ludwig, and Poldi in their recent comparison of IR reflectographic systems [7]. They analyzed CCD Si, FPA InGaAs, FPA HgCdTe, InSb detectors, and vidicon tubes. The respective upper spectral limits for these sensors are 1050 nm, 1700 nm, 2500 nm, 5 nm, and 2 nm. Using pigments modeled after those used in the 15-16th centuries, they measured the pigment transparency that could be achieved with each sensor.

Their conclusion is that InGaAs sensors are best, as they achieved high transparency values and exhibited a large gray range. However, this result only holds for underdrawings make with black, carbon-based drawing implements; since black pigments have only 2% transmittance in the NIR range, they will not be transparent for any of the five devices analyzed. For underdrawings made with iron gall inks, red crayons, or grayish inks, CCD Si cameras are probably best, since these substances are usually completely transparent over 1200 nm. Our project would focus on providing better imaging for black underdrawings only, since, for imaging other types, the best system, CCD Si, is already relatively low-cost.

Current underdrawing imaging systems that use sensors other than the cheap CCD Si require image scanning to achieve adequate image resolution. This is because their sensor arrays are small, on the order of 320 x 256 pixels; it is not economically feasible to build larger arrays. Over the past decades, scanning systems have made advances in precision of motion control and image assembly [5]. However, in the image reconstruction process, they still face difficulties with perfecting image mosaicing.

The best systems to date resemble the CPS 200E positioning system, which moves the camera while the painting stays stationary [3]. This is advantageous from an art conservation standpoint, in that it reduces wear on the painting. The CPS 200E device achieves very accurate motion. However, accurate motion alone is not enough to ensure high image quality. The complexity of the image mosaicing task also requires very precise control of lighting and knowledge about the geometric distortion produced by the exact positioning of the camera in the scanning frame. Lighting control can be achieved by imaging an illumination control card to detect inhomogeneity. Geometric distortion can be measured by imaging graph paper. The information from these two images is then merged with that of the other images during the mosaicing process.

Figure 3: CPS 200E scanner at work [3].

Aside from the camera and positioning system, the lighting mechanism is the most important element in modern underdrawing imaging systems. To reduce any damage to a painting, high-energy light, such as that from the visible and UV ranges, should be filtered out during imaging. However, the intensity of the light source must be high, since this value greatly influences the SNR of the detector. In one typical imaging setup, a pair of halogen bulbs, each with intensity in the 400 W is used [6]. The light from these bulbs is passed through an RG 1000 filter and a BG 39 filter, which sufficiently reduces high-energy radiation without damaging IR imaging potential.

The existing solutions to the various aspects of the underdrawing imaging problem - NIR detector, camera-painting positioning system, mosaicing techniques, and illumination schemes - are inadequate. They combine to make systems which, while cheaper than using a single huge NIR sensor array to take a single image, derive their economical advantage partly at the expense of system portability, accuracy, and simplicity. We intend to implement a different alternative to the single huge NIR array. Our alternative would improve upon the current solutions by reducing overall system cost, perhaps not only in monetary terms, but also in terms of portability, accuracy, or simplicity. What current systems offer for $50,000, we intend to match or beat for under $5,000 [8].

References

[1] Applications overview. http://www.sensorsinc.com/overview.html, October 2007.

[2] Casandra. http://www.prip.tuwien.ac.at/Research/Casandra/index.htm, October 2007.

[3] Cps 200e. http://www.art-innovation.nl/ventura/engine.php?Cmd=seepicture&P_site=316% P_self=450&Random=1203890474, October 2007.

[4] S. Baronti, A. Casini, F. Lotti, and S. Porcinai. Multispectral imaging system for the mapping of pigments in works of art by use of principal-component analysis. *Applied Optics*, 37(8):1299 − 1309, March 1998.

[5] D. Bertani, M. Cetica, P. Poggi, G. Puccioni, E. Buzzegoli, D. Kunzelman, and S. Cecchi. A scanning device for infrared reflectography. *Studies in Conservation*, 35(3):113–116, August 1990.

[6] A. Burmester and F. Bayerer. Towards improved infrared reflectograms. *Studies in Conservation*, 38(3):145–154, August 1993.

[7] M. Gargano, N. Ludwig, and G. Poldi. A new methodology for comparing ir reflectographic systems. *Infrared Physics & Technology*, 49:249–253, January 2007.

[8] A. Lichty. personal communication, October 2007.

[9] A. Richards. Near-ir focal-plane arrays improve camera performance. *Compound Semiconductor*, March 2003.

[10] D. Saunders, N. Atkinson, J. Cupitt, H. Liang, C. Sawyers, and R. Bingham. Siris: a high resolution scanning infrared camera for examining paintings. In R. Salimbeni and L. Pezzati, editors, *Optical Methods for Arts and Archaeology. Edited by Salimbeni, Renzo; Pezzati, Luca. Proceedings of the SPIE, Volume 5857, pp. 205-216 (2005).*, volume 5857 of *Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference*, pages 205–216, August 2005.

[11] J. R. J. van Asperen de Boer. Infrared reflectography: a method for the examination of paintings. *Applied Optics*, 7(9):1711–1714, 1968.