Projector-Guided Painting

Matthew Flagg and James M. Rehg
GVU Center, College of Computing,
Georgia Institute of Technology, Atlanta, GA
{mflagg,rehg}@cc.gatech.edu

ABSTRACT

This paper presents a novel interactive system for guiding artists to paint using traditional media and tools. The enabling technology is a multi-projector display capable of controlling the appearance of an artist's canvas. This display-on-canvas guides the artist to construct the painting as a series of layers. Our process model for painting is based on classical techniques and was designed to address three main issues which are challenging to novices: (1) positioning and sizing elements on the canvas, (2) executing the brushstrokes to achieve a desired texture and (3) mixing pigments to make a target color. These challenges are addressed through a set of interaction modes. Preview and color selection modes enable the artist to focus on the current target layer by highlighting the areas of the canvas to be painted. Orientation mode displays brushstroke guidelines for the creation of desired brush texture. Color mixing mode guides the artist through the color mixing process with a user interface similar to a color wheel. These interaction modes allow a novice artist to focus on a series of manageable subtasks in executing a complex painting. Our system covers the gamut of the painting process from overall composition down to detailed brushwork. We present the results from a user study which quantify the benefit that our system can provide to a novice painter.

ACM Classification H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General Terms Design, Human Factors, Algorithms

INTRODUCTION

In this paper, we present an interactive painting system to support novice artists in the creation of paintings using traditional media and tools. In contrast with other computer painting systems that provide tools for digital image synthesis, this work focuses on guiding users to paint according to classical techniques for creating *paintings as objects*, not just images. By employing multiple projectors to create an interactive display on the artist's canvas, our system is capable of augmenting a painting in progress with visualization features to assist with technical details such as brushstroke position, orientation and color mixing. We present a set of interaction modes designed to address common challenges for novices.
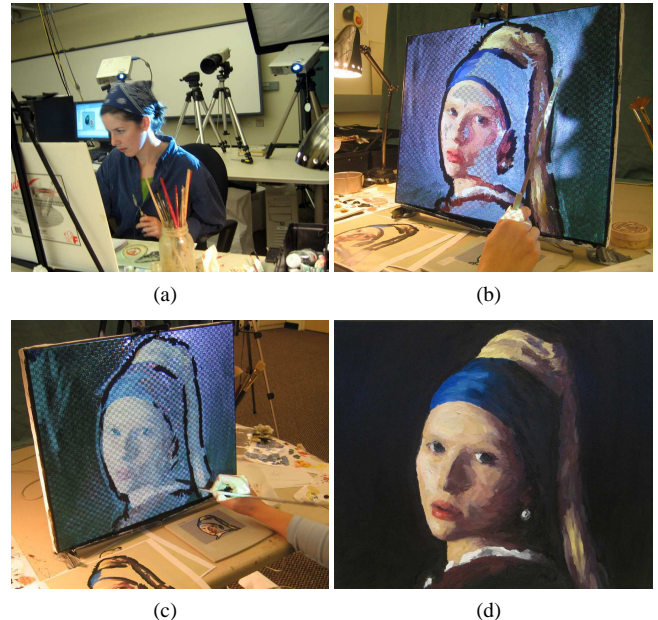
Figure 1: (a) Painting studio setup (b) Viewing a layer in *preview mode* (c) Painting the black regions of a layer in *color selection mode* (d) Final painting created using our system

Our system is part of a long history of tools for reflecting and capturing the perspective and shading of a scene as a first step in establishing the structure of a painting. Perhaps the most well-known of such tools is the *camera obscura* [22]. The modern descendant of the camera obscura is the *art projector*, a projector sold in most major art stores. The art projector is commonly used by professional painters to make accurate perspective sketches as a first step in copying originals. By replacing the art projector with video projectors and a camera, we propose using visual feedback to guide the user through the steps that follow toward creating a final desired painting.

Our system employs a multi-projector adaptive display for minimal intrusion on the traditional painter's environment in order to assist with painting technique. The display is formed on the canvas by aligning multiple overlapping front projectors. As shown in Figure 1(a), projectors are positioned on both sides of the artist to minimize the occlusion of the projected light by the artist's body. The design of our system is based on our previous work on shadow removal using redundant projection [23, 7]. Following a geometric calibration step, each pixel on the display may be illuminated by two rays of light. In addition to reducing shadows, this redundancy facilitates adaptation to the painted canvas.

An issue that arises in projecting onto a painted canvas is the need to photometrically adapt the projected image to compensate for the varying reflectance properties of the paint. We use visual feedback to incrementally adjust the projected light for each canvas pixel so as to minimize the difference between the observed and desired display color. This visual feedback approach has the advantage of avoiding the need for an explicit model of paint reflectance. Our domain is a challenging one for adaptation because the canvas is continuously changing throughout the painting process and the presence of wet paint results in specular surfaces. We note that projecting onto the canvas from behind is not an option when opaque paints such as oil and acrylic are used.

This paper makes the following contributions:

- A novel interactive system for guiding artists to paint using traditional methods and tools.
- A set of interaction modes for a canvas-centric interface which supports a traditional layer-based approach to painting.
- A novel method for creating virtual paint on a previously painted canvas, which allows artists to paint each layer without being distracted by the layers underneath.

We have conducted a user study which quantifies the benefits provided by our system over a standard art projector in assisting novice painters. We show that our system provides a significantly greater improvement in the confidence of novice painters and enables them to produce higher quality artifacts as measured by a panel of experts.

Related Work

While there is a long line of work in painterly rendering for digital images [11, 15, 8, 20, 13, 12] and the simulation of traditional media and tools for art [4, 3], to our knowledge there have only been a few systems for creating art as objects using physical tools. A robotic painting system named AARON [14] has been actively developed for three decades and its paintings have been featured in several museums and art galleries. The Everywhere Display (ED) demonstration at Siggraph in 2001 [17] guided users to create "paintings" on a table out of a collection of M&Ms. In contrast, our system is designed to support a fundamentally creative process within the framework of traditional painting practice.

Other researchers have used projector-camera systems to support spatially augmented reality [18]. Shader lamps [19], for example, used multiple projectors to illuminate complex models, such as the Taj Mahal, or animate static objects, such as toy cars. As an application of real painting augmentation, [24] use projectors for restoring colors in damaged paintings. In the work of [5], a film was applied to a painting to make the surface more amenable to displaying visualization information, such as x-ray images, directly on the canvas for display in art museums. A system described in [1] used a single portable projector to create displays that spanned multiple non-coplanar surfaces. Multiple projectors were used in [6] to boost the dynamic range of projected light in a view-dependent stereoscopic display that featured photometric adaptation to the projection surface. In contrast to these applications, the goal of our system is to support a *creative process* through the construction of a dynamic display

on the work of art as it is being developed. Our compensation approach is based on the method of [16], which addressed the problem of projecting onto photometrically non-uniform surfaces using feedback.

MOTIVATION AND GOALS

Existing tools that support the creation of works of art include books and manuals, demonstration videos, and art projectors. These tools have many deficiencies which limit their effectiveness. While books and manuals can demonstrate technique and illustrate the elements of painting style, it is difficult for the novice painter to bridge the gap between the printed page and the canvas. For example, painting manuals such as [2] demonstrate how to decompose a complex painting into a sequence of layers, but do not provide any direct support for the execution of each layer on the canvas. The execution of individual layers affects the overall composition in ways that are difficult for a novice painter to predict. It is also hard for novices to detect deviations between the painted layer and a reference picture.

In contrast to books and manuals, art projectors do provide direct support for the execution of the initial stages of a painting through their ability to project light directly onto the canvas. Art projectors are commonly used to trace or sketch onto the canvas the rough geometric forms that comprise a painting. Unfortunately, art projectors are unable to provide support to the artist throughout the entire painting process. They are also cumbersome to work with, as they lack the ability to calibrate and adapt automatically to the canvas and its contents.

The motivation for this work is the opportunity to leverage recent advances in projection and camera-based sensing technologies which make it possible to create a new projector-based painting aid. Our painting system has a number of novel features: it supports interaction directly on the canvas, it incorporates a model of the painting process, and it supports adaptation to an evolving painting through sensing and analysis of the painted content.

The target audience for our system is novices who would like to have an enjoyable painting experience while creating a high-quality work of art. Our system is designed to enable people who have never painted before to create a piece of artwork that they can be proud of. We accomplish this task by addressing, in the design of our system, the primary difficulties and pitfalls which novices encounter when working with oil paints. Note that we are not claiming to teach people how to paint or to provide a substitute for formal art instruction. Our system is part of a spectrum of painting aids which include traditional art projectors as well as instruction books and videos. Unlike these passive aids, however, our system is interactive and adaptive and incorporates a computational model of the painting process.

LAYER-BASED PROCESS MODEL FOR PAINTING

The versatility of oil and acrylic paint as an artistic medium has led to the development of highly refined processes and techniques for expressing a wide variety of artistic styles. These processes range from the quick freeform application of paint in impressionist styles to the painstaking 7-layer Flem-

ish method, a classically realist style with drying periods of months between each layer [21]. Coupled to these wide variations in the strategy for building up a painting is an equally wide range of methods for applying paint to canvas, from precisely controlled strokes or dots to the 'drip and splash' approach that characterized Jackson Pollock's work.

The design of our system is based on the following two assumptions about the process of painting in acrylics and oils:

- We assume that paintings will be planned out in advance of execution and decomposed into a series of layers that can be applied to the canvas in linear order (back to front).
- When painting each layer, we assume that the artist will want to apply paint to the canvas in an orderly, sequential manner and will base their palette on the color scheme for the layer and the desired amount of manipulation.

Under these assumptions, a painting consists of the execution of a series of layers. Therefore, our system adapts a layer-based representation. In painting each layer we assume that the artist will mix one or more desired paint colors, select an appropriate brush or knife, and load it with paint. The artist then chooses a region of the layer corresponding to the selected color, applies the paint, and manipulates it until the desired effect has been achieved. Thus a layer is painted region-by-region until it is complete. The interaction modes described on the next page are designed to support each of these tasks. While our approach can apply equally to acrylic paints with minimal modification, for the purpose of our discussion and experiments we will confine ourselves to painting in oil.

Our model of the painting process is consistent with a number of classical and popular painting styles. Traditional layer-based oil painting methods are characterized by long drying times, which can be accelerated by thinning the paint heavily with turpentine, as in the "fat over lean" approach [10]. In these layer-based methods, wet paint is applied on top of existing layers of dry paint. An alternative is the Alla Prima method of wet-into-wet, which was popularized by Impressionist painters like Edouard Manet. In this approach paints are applied in rapid succession without intervening drying times. The goal is to achieve decisive, clean strokes which remain visible in the final painting. Although the Alla Prima method is not limited to a layer-based painting approach, it is compatible with our layer-based computational representation. Brushstrokes will often follow a progression in both size and color as early layers tend to consist of broad general strokes, followed by a progression of detail. Cézanne's advice, cited in [10], was to "start with the broom and end with the needle!". Similarly, the more opaque light paints are frequently applied after the darks. For the purpose of testing and evaluating our painting system, we have adopted the Alla Prima method, as the shorter drying times facilitate experimentation and the immediacy of the technique is appealing to beginners.

The layers which our painting model requires can come from a variety of sources. One possibility is to capture the painting process of an experienced artist. In addition, layers can be scanned in from painting manuals and registered. We can also use painterly rendering techniques to create layers auto-matically from photographs or 3-D models. One of the example paintings from our video submission uses the method of Hays and Essa [12] to generate layers from an input photograph, by rendering brushstrokes along contours which are generated by a multi-scale edge detector. Low frequency edges are rendered with wider brushstrokes and high frequencies are rendered with narrower ones.

CHALLENGES FACED BY NOVICE PAINTERS

Novice painters face a variety of challenges in executing a complex painting, including the difficulty of positioning and sizing the elements of the composition on the canvas, the challenge of executing the required brushstrokes, and the complexity of mixing paints to achieve the desired colors. For example, as described in [10], inexperienced painters often make the mistake of working on one small area of a painting until it is finished and then move on to the next area. This can result in a "confused and disjointed image because each area of tone and colour is separate and unrelated to its neighbors." Our adoption of a layer-based approach and the development of interaction modes which support the execution of individual layers addresses this concern.

The desired look of the painting is achieved through careful control of the brush, by regulating the pressure, movement, speed, and distance of each stroke. Impasto, for example, is a technique for producing a "fresh, vigorously textured look" [21] using thick, expressive brushstrokes. Smith [21] recognizes the difficulty of applying brushstrokes to generate the characteristic impasto texture in a uniform manner throughout a layer. This is an example of the larger class of problems novices may face at the brushstroke application level. Our system can provide guidance in the application of brushstrokes to create a desired effect.

Color mixing is one of the most difficult tasks faced by a novice painter. The proportions of paints which must be combined will vary dramatically from one shade of color to the next, and most beginning painters are unfamiliar with the subtleties of the subtractive color space that governs the paint mixing process [9]. In our observations, users can easily spend 20 minutes or longer in an attempt to reproduce a specified color for a particular painting. These long delays are a source of frustration, particularly when users must re-mix a given color after running out of it. Our system includes support for color mixing by automatically identifying the components that are required for a particular color and adaptively guiding the mixing process.

INTERACTION MODES

Our system is designed around a set of interaction modes that assist the artist in painting the ordered set of layers that comprise a finished painting. We support hands-free switching between interaction modes using a foot pedal (see the included video for example usage). Each interaction mode is realized by projecting light onto the surface of the painting itself and adapting the projection to existing paint on the canvas in creating the desired display. We describe our adaptive projected display in the following section. Our system provides five interaction modes to support the painting process:
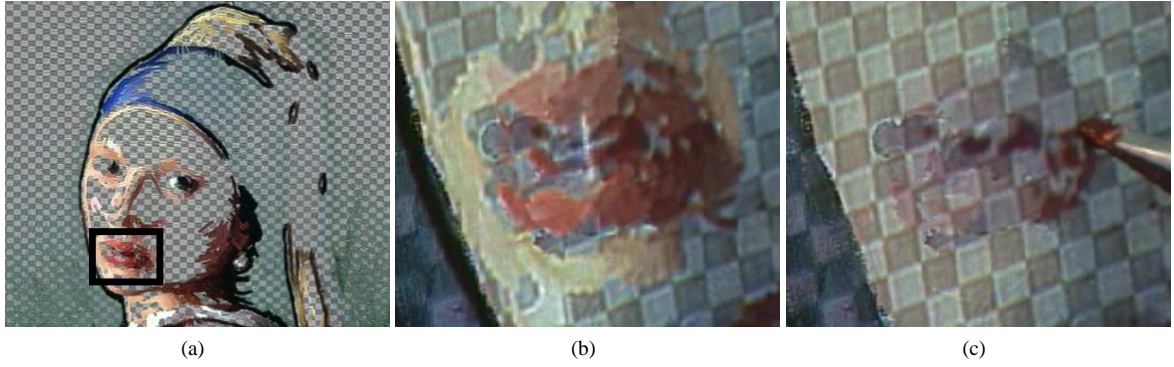
- **Preview Mode** to display layers

Figure 2: (a) Layer 4 out of 4 in preview mode, with highlighted region around lips. (b) Closeup of lip region. (c) Lip region following color selection. Note that all images are photographs of the actual canvas under compensation.

- **Color Selection Mode** to paint with specific colors
- **Blank Mode** to assess the state of the painting
- **Orientation Mode** to display brushstroke guidelines
- **Color Mixing Mode** to aid in creating the desired colors

Preview Mode: A visual guide for painting a given layer is provided by preview mode, which creates an overlay on the canvas that displays the current layer in progress while compensating for the underlying paint. The use of this mode is depicted in Figs. 1(b) and 2(a). In preview mode, areas of the canvas that are not to be painted in the current layer are hidden from the artist using a checkered pattern. This pattern is easily distinguished from the foreground elements of the layer. This reduces the chance that regions outside the current layer will distract the artist from a particular execution step.

Furthermore, the clear visibility of all layer regions and "invisibility" of off-layer regions provided in preview mode helps the artist devise a strategy for selecting a color palette and set of brushes that are used to paint the layer. For example, it may be the case that each layer corresponds naturally to one specific brush size. It is easy to select a brush in preview mode by physically comparing brushes to their previewed strokes on the canvas.

Color selection mode: Another challenge in executing a particular layer is the efficient use of paint. An artist with a loaded brush would like to quickly identify regions of the canvas that need that particular color. To address this need, we designed a color selection mode that highlights all strokes of a chosen color in the current layer. The artist uses a Wacom tablet with a pen attached to the opposite end of the paintbrush to select a specific color in the layer. Figs. 1(c) and 2 illustrate the use of this mode. The white cross in Fig. 2(b) indicates the selection of a particular shade of red in the layer containing the girl's lips. We employ a user-specified tolerance parameter to determine which parts of the layer match the selected color. The tolerance is adjusted interactively via the foot pedal, to expand or contract the color region of interest.

Following color selection, all other colors are hidden from view so that the artist can apply the color where it is needed. A comparison between Fig. 2(b) and 2(c) demonstrates that color selection mode effectively masks out regions in the layer which do not correspond to the selected color. For areas like these where it is difficult to distinguish between various shades of red, the color selection tool is useful for clearly marking where paint should be added.

Blank mode: The artist can systematically complete each layer through the use of the preview and color selection modes. In order to assess the progress made in painting a layer, along with the current state of the painting, the artist may switch the projectors off at any time using blank mode. The included video shows the utilization of preview, color selection, and blank mode in completing a layer.

Orientation mode: While preview and color selection modes show the artist *where* to apply paint, orientation mode shows the artist *how* to apply it. A set of guidelines overlaid on the layer indicate the orientation, width, and extent of brushstrokes that should be applied to achieve a desired brushstroke texture. For example, long, linear guidelines would indicate the need for bold, expressive strokes, while a short hatching pattern would indicate the use of a dabbing technique. Guidelines can also be used to indicate directions for blending paints, as depicted in Figures 4(b) and 4(c). Orientation guidelines must be generated along with their associated layer images. We note that one benefit of using the painterly rendering method of Hays and Essa [12] to produce layers is that it automatically generates contours that can be used as orientation guidelines.

Color mixing mode: Support for the task of combining paints to achieve a desired color is provided by color mixing mode. Fig. 3 shows the interface, which depicts a standard color wheel along with a camera view of the artist's palette. Using the Wacom tablet, the user identifies an area on the palette where paint is to be mixed. A desired color from the current layer can be specified via color selection mode. A precalibrated table maps the target color to a specific location on the color wheel, known as the target point. Labeled source points on the color wheel correspond to fully-saturated source pigments (labeled "18" and "24" in Figure 3).

The first step in mixing the target color is to identify the fully saturated colors that may be combined to make the target color. For any point on the color wheel, the system selects the two colors that lie on both the outer boundary of the color wheel and on a line connecting the center of the wheel to the
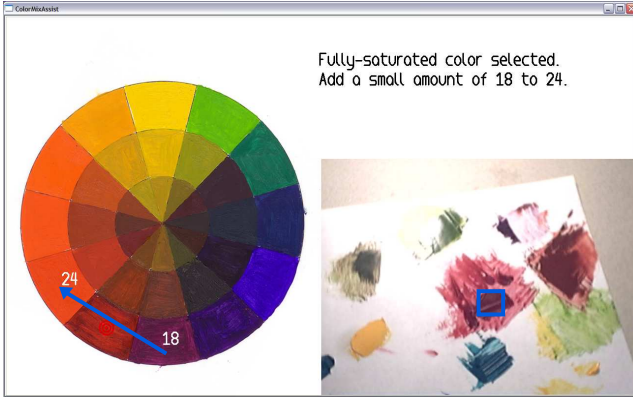
Figure 3: Interface for *color mixing mode*, which employs automated capture of and localization of palette colors on a color wheel to guide the paint mixing process. The blue arrow illustrates the movement of the current mixture color, which is the selected region in the camera image, to the desired target.
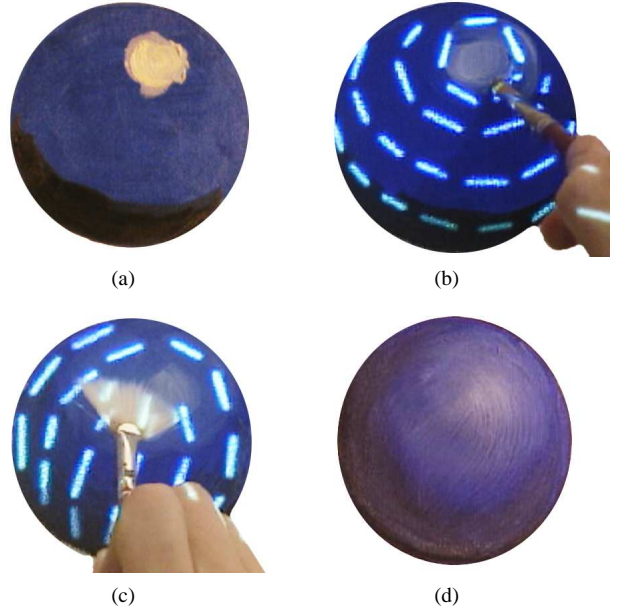

Figure 4: Painting a sphere using orientation mode. (a) Sphere with highlight and shadow; (b) Coarse blending with bristle brush in orientation mode; (c) Fine blending with fan brush in orientation mode; (d) Finished result.

target color's location on the wheel. These two fully saturated components of the target color are complementary colors. Following identification of these two ingredient colors, the user may put a sample of the color on the palette directly from the tube or by means of another mixture process. The interface may be used to help mix these source ingredients if needed. After both ingredient colors have been placed on the palette, one color is gradually mixed with the other. Following each step of paint addition, the camera image is analyzed to identify the point on the model color wheel which corresponds to the mixture in progress. Estimation of the mixture point is accomplished using a pre-calibrated set of histograms obtained for a representative set of pigments. These points chart the geometric progress of moving the color along a gradient on the color wheel. The system guides the user to slowly add one ingredient color to the other to achieve the desired target point.

CREATING A DISPLAY ON A PAINTED CANVAS

We employ a system of two projectors and one camera to create an adaptive display directly on the canvas. The projector outputs and camera input can be automatically warped and aligned with the surface of the canvas using standard calibration methods [7].

Multi-Projector Adaptive Display: By placing the two projectors at an oblique angle to the canvas and overlapping and aligning their outputs, we gain the ability to illuminate each pixel on the canvas with two distinct sources of light. This has two benefits. First, by projecting simultaneously from both projectors we gain robustness to shadows and occlusions, as described in [7]. Second, by adapting with both projectors during compensation, we can increase the dynamic range of the display on the canvas. This is particularly useful in trying to adapt dark colors to make them lighter.

Photometric Adaptation: In order to control the appearance of the canvas, our system must account for the spatially varying reflectance of a painted canvas. Any image projected onto the canvas will be modulated by the reflectance of the paint and therefore create an undesired appearance as shown in Fig. 5(d). To achieve a desired appearance, we adapt a feedback approach in which a captured camera image of the canvas is analyzed to create a compensation image for each projector to output.

Our compensation approach is based on the method of Nayar et. al. [16] for adapting the output of a single projector to a surface with varying reflectance. Our system employs multiple projectors to increase the dynamic range of the compensation method and supports the positioning of the projectors beside the artist instead of directly in front of the canvas. The algorithm works by projecting an initial input image and iteratively adjusting image intensities using visual feedback. Starting with all projectors projecting black, each projector iteratively reduces compensation error, the difference between desired and measured intensities for each pixel and channel independently, according to the proportional feedback law $P_{i+1} = k(I - C_i) + P_i$, where P_i is the compensation image for iteration i, I is the desired appearance image, C_i is the surface-aligned camera image for iteration i, and k is the gain. Once the error has dropped below a threshold tolerance, a completion mask is toggled for the finished pixel to avoid further adjustment of its compensation intensity. Adaptation halts after the change in error for all pixels has stabilized or a maximum number of iterations have occurred. Following adaptation, the compensation image for the current projector is fixed and adaptation begins for the next projector. Each subsequent projector reduces error for the remaining pixels that have not met the target intensities for each channel. Figure 5 illustrates the compensation process for 2 projectors positioned as in Figure 1(a). Clearly, the appearance of the canvas is closer to the desired image with two projectors than with one. These results establish the effectiveness of compensation in the case of oil paints.
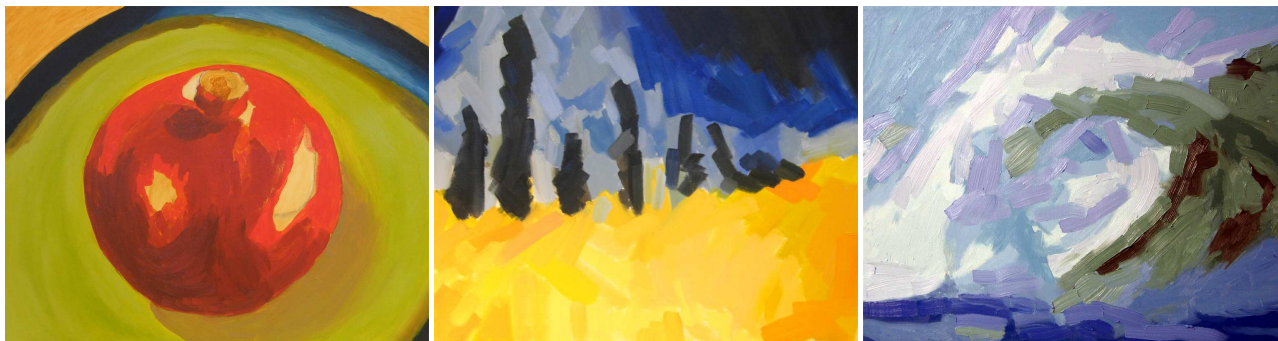
Figure 6: 3 paintings made using our system by 3 painters who had never painted before.

RESULTS

We present the results of a formal user study of novice painters along with informal observations on the usage of our system by several subjects.

User Study

We conducted a formal user study to quantify the benefit that our system can provide to a novice painter, relative to a standard art projector. The study had two components. In the first component, a population of twenty subjects was asked to paint copies of the model painting illustrated in Fig. 8(b).[1] Each of the subjects was given a canvas containing an initial sketch of the desired shape (as produced by a standard art projector) and printouts of the model painting. Ten of the subjects served as a control group and produced their paintings without the use of our system. The other ten subjects had full access to our system.

Prior to their painting experience, each subject filled out a questionnaire in which they were asked to rate their confidence in their ability, on a scale of 1 to 5 where 1 means "not confident at all" and 5 means "very confident", to paint a set of three paintings which were identified by an art expert to be of low, medium, and high difficulty.[2] The questionnaire also contained questions to assess whether the subject had any previous painting experience.[3] (Subjects with prior experience were allowed to complete their paintings but one was dropped from the analysis due to experience.) Each subject was then given a brief orientation session and then asked to paint a short warm-up painting which took approximately 15 minutes.[4] Each subject then completed the model painting, which took three hours on average.

Following their painting experience, the subjects filled out a second survey which again asked them to rate their ability to execute a different set of three paintings of equivalent levels of difficulty. In addition, subjects were asked to rate their level of frustration, level of boredom, likelihood to paint again, assessment of the quality of their painting, and overall satisfaction with the experience, on a scale of 1 to 5.

We conducted an analysis of the self-assessed ability ratings for each subject population before and after their painting experience. The average prior confidence rating for the painting of Medium difficulty was 2.2 for the control group and 2.3 for the group that used our system. Following their painting experience, the average rating for the Medium difficulty painting dropped to 1.6 for the control group, and rose slightly to 2.5 for the group that used our system. We ran a t-test and Mann-Whitney-U nonparametric test for the null hypothesis that there was no significant difference in the dependent variables between the two groups. The difference in assessed ratings was found to be statistically significant (at level $p < 0.05$) using both tests. We conclude that our system has a quantifiable, positive benefit over what an art projector alone can provide in improving the confidence of novice users.[5]

In the second component of the study, a group of three experienced painting professors filled out two questionnaires to evaluate each of the twenty paintings completed by the novice users (see Fig. 8). The first questionnaire asked respondents to rate 6 attributes of painting quality on a scale of 1 to 7 and the second questionnaire asked the professors to rank their top ten paintings in terms of overall quality and overall similarity to the model painting.[6] Fig. 7 reports the sum of the ranks of expert ratings for six survey attributes over the two populations of paintings, where 1 = "poor quality", 4 = "medium quality" and 7 = "high quality." The p-values for the Mann-Whitney-U test are shown for each attribute. A statistically significant difference (at $p < 0.05$) was observed for every attribute except "quality of color matching to original painting." Furthermore, a majority of the top 10 paintings ranked by each professor were painted with the use of our system. These results serve to further validate our

---

[1]An experienced artist created the barn image in two layers with associated orientation mode guidelines. The captured layers and guidelines were used by our system.

[2]The paintings used in our survey were as follows: Before painting, difficulty *Low* "Composition with Red, Blue, and Yellow" (Mondrian), *Medium* "The Lemon" (Manet), and *High* "Floor Scrapers" (Caillebotte). After painting, difficulty *Low* "Number 10" (Rothko), *Medium* "Dusk" (Monet), and *High* "The Music Lesson" (Vermeer).

[3]All questionnaires and raw data are available at http://www.cc.gatech.edu/cpl/projects/painting

[4]The warm-up session was conducted to help eliminate any negative effects of using basic painting tools for the first time.

[5]The average confidence ratings for the Low and High difficulty paintings did not show a statistically significant variation between the two groups. However the mean ratings for both attributes were higher for the group that used our system. Note that the model painting was designed to be of medium difficulty.

[6]In addition to ranking the paintings, the second questionnaire asked for open comments on standard attributes they have used in the classroom for comparing paintings and assessing their relative quality. These comments were found to validate our choice of survey attributes for the quality of the painting and its similarity to the model.
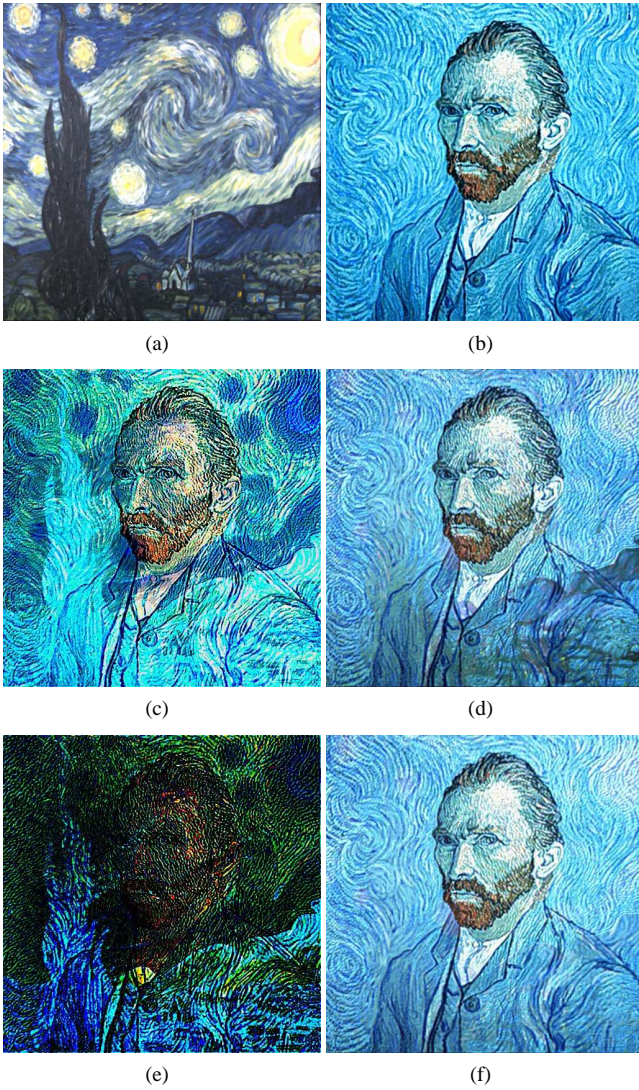
Figure 5: (a) Canvas before compensation; (b) Desired appearance; (c) Projector 1 compensation image; (d) Compensation result for projector 1 alone; (e) Projector 2 compensation image; (f) Final canvas appearance under the combination of projectors 1 and 2.

claim that our system can help novice painters to produce higher-quality artifacts than an art projector alone.

Usage Trends

Figure 6 shows three paintings created using our system by three novice artists who had never painted in oils before. Each painting took an average of 5 hours to create using our system. We observed the painting process for these artists and identified the following trends:

First, two of the subjects exhibited initial hesitation in applying the brushstrokes directly on top of the displayed virtual brushstrokes. For the two impressionist style paintings in Figure 6, for example, both artists applied the paint in very small and slow brushstrokes despite the implicit instruction to paint with quicker and more sweeping brushstrokes as visually suggested in preview, color selection and orientation modes.
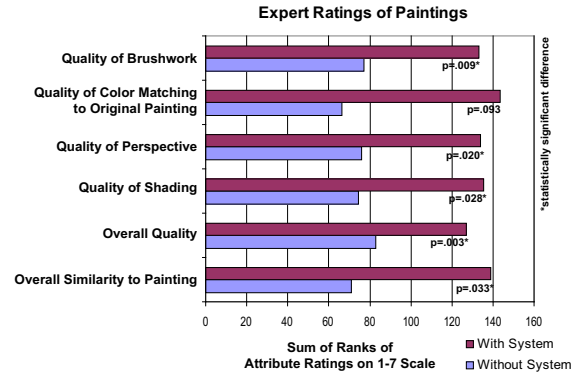

Figure 7: Aggregate quality ratings reported by three painting professors, for the two sets of paintings shown in Fig. 8.

Second, as the novices' hesitations faded and they switched between interaction modes more frequently, task execution speed increased. This indicates that they learned how to apply regions of color in a layer in a more effective manner and, as a result, became more confident in their ability to accomplish painting goals.

Third, as the paintings progressed, all three users switched to color selection mode more frequently. In one case, the artist repeatedly re-adjusted the color similarity tolerance for each color selection before applying a new color to the canvas. This enabled him to grow or shrink the layer segmentation until it appeared to conform to contiguous brushstroke areas as opposed to pieces of brushstrokes resulting from color variation across the brushstroke. This behavior suggests the need for a more sophisticated means of detecting and segmenting brushstrokes for color selection mode.

We were initially concerned about the potential negative effects of glare and shadows on the subjects in our experiment. Glare caused by projecting light onto wet oil paint could both hinder the ability to control the appearance of the canvas using photometric compensation and annoy users of our system. Shadowing on the display due to projector occlusions by the artist could prevent the effective use of interaction modes for painting guidance at the color application and manipulation level. We found that by positioning our projectors at oblique angles, we were able to reduce both of these effects in practice. None of the artists reported any discomfort caused by glare or shadows.

CONCLUSION AND FUTURE WORK

We have described a novel interactive system for guiding novice artists to paint using traditional methods and tools. We have demonstrated how a multi-projector adaptive display can support artistic painting by guiding users according to traditional painting techniques taught in artist's manuals. Furthermore, we presented a set of five interaction modes for a canvas-centric interface which supports a traditional layer-based approach to painting. We evaluated the effectiveness of our system in meeting the goals of improved quality of experience and high quality of output. The results of our user study indicate that these goals were met.

(a)

(b)

(c)

Figure 8: **(a)**: *Top two rows:* Paintings made with the system. *Lower two rows:* Corresponding zoomed-in regions for the paintings in the top rows. **(b)**: Model painting all subjects in the user study were told to copy **(c)**: *Top two rows:* Paintings made without the system. *Lower two rows:* Corresponding zoomed-in regions for the paintings in the top rows. Notice the larger deviation in shading from the model for the zoomed in portion between the two groups.

Our system has the flexibility to handle a wide range of painting styles and approaches. Portraiture, still life, and landscape paintings are examples of domains that are supported by our process model. However, Jackson Pollock's paintings provide an example of a less traditional means of applying paint that does not fall within the range of techniques that we currently support.

In future work, we are considering extending the painting interaction techniques presented in this paper to other areas of the fine arts. Multiple projectors could guide a sculptor in subtracting material from a block of marble, for example. Just as layers were used to build up the composition of a painting in the current system, a sculpting system could guide an artist in a hierarchical broad-to-fine chiseling approach.

REFERENCES

1. M. Ashdown, M. Flagg, R. Sukthankar, and J. Rehg. A flexible projector-camera system for multi-planar displays. In *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, volume 2, pages 165–172, 2004.
2. Barron. *All About Techniques in Oil*. Barron's Educational Series, Inc., 1997.
3. W. Baxter, V. Scheib, M.C. Lin, and D. Manocha. dab: Interactive haptic painting with 3d virtual brushes. In *Proceedings of Siggraph*, pages 461–468, New York, 2001.
4. W. Baxter, J. Wendt, and M. Lin. Impasto: A realistic, interactive model for paint. In *Proceedings of the 3rd International Symposium on Non-Photorealistc Animation and Rendering*, pages 45–56, New York, June 2004.
5. O. Bimber, F. Coriand, A. Kleppe, E. Bruns, S. Zollmann, and T. Langlotz. Superimposing pictorial artwork with projected imagery. *IEEE MultiMedia*, pages 16–26, January-March 2005.
6. O. Bimber, G. Wetzstein, A. Emmerling, and C. Nitschke. Enabling view-dependent stereoscopic projection in real environments. In *In proceedings of International Symposium on Mixed and Augmented Reality (ISMAR'05)*, pages 14–23, 2005.
7. T.-J. Cham, J.M. Rehg, R. Sukthankar, and G. Sukthankar. Shadow elimination and occluder light suppression for multi-projector displays. In *Proceedings of Computer Vision and Pattern Recognition*, pages 513–520, 2003.
8. C.J. Curtis, S.E. Anderson, J.E. Seims, K.W. Fleischer, and D.H. Salesin. Computer-generated watercolor. In *Proceedings of Siggraph*, pages 421–430, 1997.
9. B. Edwards. *Color: A Course in Mastering the Art of Mixing Colors*. Penguin Group (USA) Inc., 2004.
10. A. Gair. *The Artist's Handbook: A Step-by-Step Guide to Drawing, Watercolor and Oil Painting*. MetroBook, 1998.
11. P.E. Haeberli. Paint by numbers: Abstract image representations. In *Proceedings of Siggraph*, pages 207–214, 1990.
12. J. Hays and I. Essa. Image and video based painterly animation. In *Proceedings of the 3rd Symposium on Non-Photorealistc Animation and Rendering*, pages 113–120, New York, 2004.
13. A. Hertzmann. Painterly rendering with curved brush strokes of multiple sizes. In *Proceedings of Siggraph*, pages 453–460, 1998.
14. P. McCorduck. *Aaron's Code: Meta-Art, Artificial Intelligence and the Work of Harold Cohen*. W H Freeman and Co., 1990.
15. B.J. Meier. Painterly rendering for animation. In *Proceedings of Siggraph*, pages 477–484, 1996.
16. S. Nayar, H. Peri, M. Grossberg, and P. Belhumeur. A projection system with radiometric compensation for screen imperfections. In *First IEEE International Workshop on Projector-Camera Systems (PROCAMS-2003)*, 2003.
17. C. Pinhanez, R. Kjeldsen, T. Levas, G. Pingali, M. Podlaseck, and P. Chou. Ubiquitous Interactive Graphics. Technical Report RC22495 (W0205-143), IBM Research Report, May 2002.
18. R. Raskar, G. Welch, and H. Fuchs. Spatially augmented reality. In *First IEEE Workshop on Augmented Reality (IWAR'98)*, 1998.
19. R. Raskar, G. Welch, and K.-L. Low. Shader Lamps: Animating real objects with image-based illumination. In *Proceedings of Eurographics Workshop on Rendering*, 2001.
20. M.P. Salisbury, M.T. Wong, J.F. Hughes, and D.H. Salesin. Orientable textures for image-based pen-and-ink illustration. In *Proceedings of Siggraph*, 1997.
21. R. Smith, M. Wright, and J. Horton. *An Introduction to Art Techniques*. DK Publishing, Inc., 1995.
22. Philip Steadman. *Vermeer's Camera: Uncovering the Truth behind the Masterpieces*. Oxford University Press, 2002.
23. J. Summet, M. Flagg, T.-J. Cham, J.M. Rehg, and R. Sukthankar. Shadow elimination and blinding light suppression for interactive projected displays. *IEEE Transactions on Visualization and Computer Graphics*, Accepted for publication in 2006.
24. T. Yoshida, C. Horii, and K. Sato. A virtual color reconstruction system for real heritage with light projection. In *Proceedings of International Conference on Virtual Systems and MultiMedia*, 2003.