Laser Cut Layered Gels for Lighting Design

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Abstract
Recent advancements in lighting design have focused on the visualization and simulation of programmable LED lighting fixtures. However, single-bulb conventional fixtures alongside subtractive color filter gels are still widely used in many art galleries and installations, photography studios, and experimental theatres due to their low cost and existing prevalence in industry. We introduce a novel approach to creating lighting effects for single-bulb fixtures with gels, which enables designers to quickly and inexpensively produce complex, multi-colored effects approximating a target digital image. Our system uses a grid-based approach which cuts small openings in different colored gels and layers them together, forming color combinations when lit. Our work expands the design space of lighting gels with a precise and expressive method, enabling designers to experiment with novel lighting effects through an iterative personal fabrication process.

Author Keywords
Digital Fabrication; Lighting Design; Rapid Prototyping

CCS Concepts
•**Applied computing** → **Media arts;** Performing arts; •**Human-centered computing** → *Interactive systems and tools;*

Figure 1: A standard conventional fixture [a].

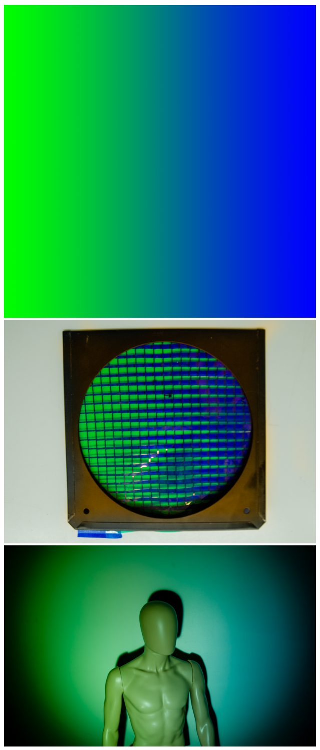

Figure 2: The entire process of designing a blue/green gradient gel. Top: Target image. Middle: Cut gels in a gel frame. Bottom: The lit result on a human-sized mannequin for scale.

Introduction

Lighting designers in many domains—theatre, photography, film, and installation art, to name some—use stage lighting equipment to create a wide range of lighting effects. Lighting design can direct a viewer's attention, convey a sense of mood or atmosphere, communicate a time of day, or signal a narrative or emotional cue. While lighting design has long been used as a storytelling medium through techniques such as shadowplay, "Magic Lantern" image projection, and cast bronze inscribed mirrors [5], modern lighting designers utilize electric fixtures to achieve a wide range of lighting effects. To achieve such effects, designers use two kinds of lighting fixtures: LED fixtures, which let designers dynamically control colors through software, and conventional fixtures, which have a single white lamp (Figure 1). While designers can modulate a conventional light fixture's intensity through a control board, designers use *gels* —thin, colored plastic filters—to achieve specific colors. Most 6" gel squares cost less than $1 [9] and are commonplace among theatre, film, and photography sets. Single gels are loaded into a metal *gel frame* at the end of a conventional fixture and create color by subtractively filtering outgoing light. To mix colors, designers can use multiple fixtures and achieve convincing gradients by pointing them at the same place or with a small offset. To create patterns or specific images, lighting designers place custom-made colored glass slides, called *gobos*, inside fixtures. These slides can selectively color and refract a fixture's light.

Custom gobos cost at minimum $100 for a single color and up to $700 for multiple colors, and require manufacturing and shipping times of several weeks [4, 6]. Due to this cost and time, designing, experimenting, and iterating with gobos is challenging. The cost and labor associated with designing and operating large arrays of fixtures is also high——a standard conventional fixture costs about $500 and an LED fixture is at least $2000 [10]. While designers sometimes create custom lighting gels to achieve simple multi-color effects for conventional fixtures, they do so by hand-cutting out shapes with scissors or a cutting blade and the taping pieces together. This process not only limits the precision of resultant patterns, but its high labor intensity makes iterating on patterns slow.

Our target audience is lighting designers who use a single conventional fixture, which is cheaper, does not require dynamic control, and still present in many spaces. These designers often iterate on lighting effects within their physical spaces instead of within visualization software, as they often create unique, precise lighting effects—which can be difficult to visualize due to subtle interactions with materials such as fabric, skin, and glass—requiring careful trial and error to perfect. As laser cutters are already common among scene shops for set construction as well as makerspaces, woodshops, and art studios, we expect laser cutter access not to be a barrier.

We present a tool for designing multi-colored lighting effects with laser-cut, layered gels for a single conventional light source. By utilizing a laser cutter and basic gels, our method extends the capability of a single conventional fixture, using 6" gel squares which cost less than $1 each and are cut in about 15 minutes on a standard laser cutter. With our method, lighting designers can produce multi-colored and gradient effects more quickly and cheaply than with a glass gobo or multiple lights, while taking advantage of the precision of a CNC tool over existing hand-cut solutions. We present a grid-based algorithm that takes arbitrary RGB images as input, enabling designers to create effects using familiar image editing software. Our algorithm approximates a target image by dividing it into a grid, and, for each grid cell, creating a pattern such that the amount of each gel vis-

[a]Image Source: Wikimedia Commons

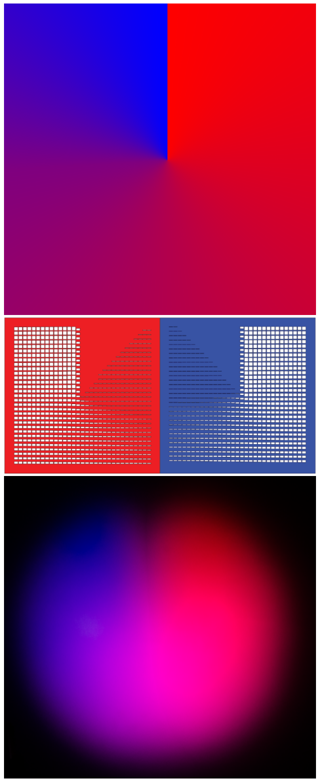

Figure 3: Top: A red/blue circular gradient target image, input to our system. Middle: The red and blue cut gel patterns our system outputs. Bottom: The lit result of the gels affixed to a conventional fixture.

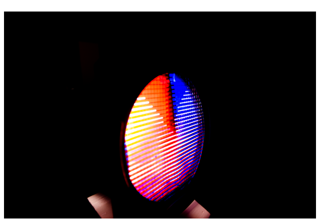

Figure 4: The red and blue gels in Figure 3 layered together in a gel frame and placed in front of a conventional fixture.

ible for transmission by the light source corresponds to the color of the target image cell. We contribute a novel method for lighting design that converts a digital image to a multi-colored gel pattern.

Related Work

Previous HCI research into lighting design has largely focused on pre-implementation visualizations of stage lighting or novel systems for designing complex lighting configurations from large fixture arrays. Following formative work in visualization tools for lighting designers [2], recent systems enable designers to "paint" illumination onto a digital image, configuring either an array of LED light fixtures placed around an object [1] or a single moving white light [7]. Specific to theatrical design, Shimizu et al. enable the designer to provide color and style reference images to a system which automatically generates lighting configurations for tens or hundreds of LED fixtures [13]. While we also start from a digital image, we instead focus on extending the capabilities of a single conventional fixture, enabling designers to create more complex effects without increasing the cost.

Our system is also motivated by research into novel design tools in personal fabrication. While some systems focus on new ways to interact with a laser cutter, such as interactive fabrication directly on the workpiece [8] or multilayered design and construction [15], others utilize laser cutters in domain-specific design tools, such as furniture construction [11], hand-sketched 3D objects [16], or selectively heating and engraving food [3]. Our system falls into this second category, as we develop a specialized design tool for laser cutting gels.

Outside of laser cutting, Torres et al. present work on designing 3D-printed light fittings [14]. We share the authors' focus on a "material and space-driven exploration of light," although our work looks at producing specific projected effects from a light source onto a subject (such as a person, wall, or stage), instead of lighting effects viewed directly.

Design Goals

Professional, large-venue lighting designers visualize and pre-program lighting configurations of tens or hundreds of LED and conventional fixtures within software packages often before any physical fixtures are installed.

Lighting plots, colors, and animations are digitally designed and programmed often before any physical lighting fixtures are brought into a venue. This tool does not seek to improve the workflows of those designers. We instead focus on small-scale lighting designers in places such as galleries, photography studios, or experimental theatres. These smaller-scale designers often have time to experiment and iterate within a physical space, but lack the resources to buy many fixtures or the labor required to manage them. Thus, we prioritize quick and cheap physical iteration over visualization.

From informal interviews with lighting designers and the first author's experience in technical theatre, hand-cut gels are currently sparingly used because of the manual construction time required and the difficulty in creating a gel beyond very basic, two or three segment designs. Therefore, our system should offer precise, reproducible results with minimal manual construction, enabling for greater detail and complexity than what is currently achievable by hand.

Following Torres et al. [14], we also seek to increase the expressiveness of lighting design tools, widening the design space of lighting with gels while matching our system interactions into existing workflows as seamlessly as possible. Thus, our method should only take a color image as input and should have minimal parameter tweaking required

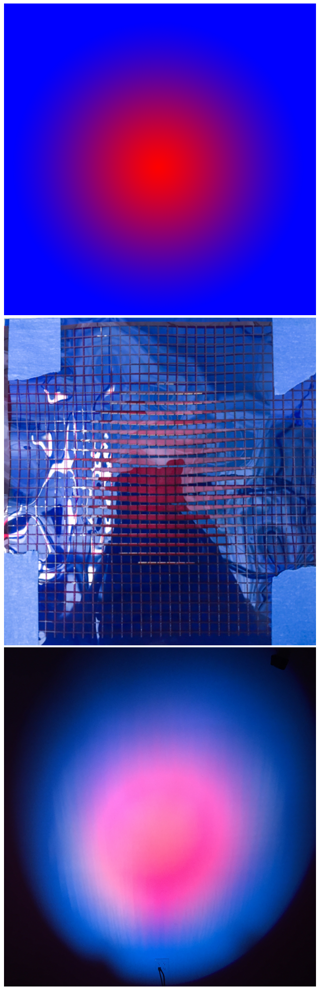

Figure 5: Top: Target image of a red center and blue background. Middle: The corresponding layered gels taped on a gel frame. Bottom: The lit result of the above gels.

outside of an image editor.

Our system should seek to broaden the range of lighting effects possible with gels and conventional fixtures while not diverging from existing workflows.

In summary, our design goals are Iteration: The tool should use relatively cheap and widely-accessible materials, leverage a common CNC tool, and not require complex handmade assembly. Precision: the tool should offer significantly greater precision over what is achievable by hand. Expressiveness: the tool should widen the design space of lighting design with conventional fixtures and gels without disrupting existing design workflows, such as the use of common image editors.

System Description

Our algorithm takes as input an RGB target image and outputs two vector files for laser cutting which approximate the target image as projected light. With a light source with sufficiently scattered rays (such as a conventional fixture), we expect that, when small regions of two gels are positioned alongside one another, light will pass through both gels such that the final projected region is a mixture of both. This produces a final color proportional to the area of each gel. With a square grid shape, the system currently supports the mixing of two color gels, and so while a standard RGB image can be taken as input, only two RGB channels will be represented: C_1 and C_2 (blue and red in Figure 3).

After creating their desired projection in their favorite image editor, designers input their target image to our algorithm (implemented in a Processing Application [12]) and select two color channels of interest. Our algorithm then splits the target image into a grid (for a 6" x 6" filter we have used 30x30 cells for the designs shown). For each grid cell, we compute the average color for $(C_1, C_2) \in [0, 1]$ in addition to the average saturation S and lightness L of all pixels in the cell, where saturation and lightness are calculated as:

$$S = \begin{cases} 0, if MAX = 0 \Leftrightarrow R = G = B = 0 \\ 0, if MIN = 1 \Leftrightarrow R = G = B = 1 \\ \frac{2MAX-2L}{1-|2L-1|}, otherwise \end{cases}$$

$$L = \frac{MAX + MIN}{2}$$

Where $MAX = max(C_1, C_2)$ and $MIN = min(C_1, C_2)$. We then multiply C_1 and C_2 by the average saturation S $\in$ [0,1] for $F_1 = C_1 * S$ and $F_2 = C_2 * S$. For each cell in the gel corresponding to C_1, we then create a partial rectangle proportional to $F_1 \in$ [0,1], where F_1 = 0 would indicate a fully cut out cell and F_1 = 1 would be a cell entirely covered over by the gel with no cutting. We then repeat this process for C_2. Our current approach uses .6mm as the minimum spacing between two cells. For greater control, designers can optionally map F to an exponential curve which can correct for a lamp color (usually a warm yellow instead of white), or correcting for gels which don't perfectly approximate a primary color.

The designer then receives two SVG files to laser cut. They align the cut gels, tape their edges together, and install them in a gel frame alongside a minimal diffuser gel, which scatters the light just enough to remove any slight visible grid lines from the projected image.

Discussion

Our work describes a novel approach for creating lighting effects with widely-accessible materials in an iterative, precise, and expressive system. Because our system utilizes a grid-based pattern executed by a rapid prototyping tool,

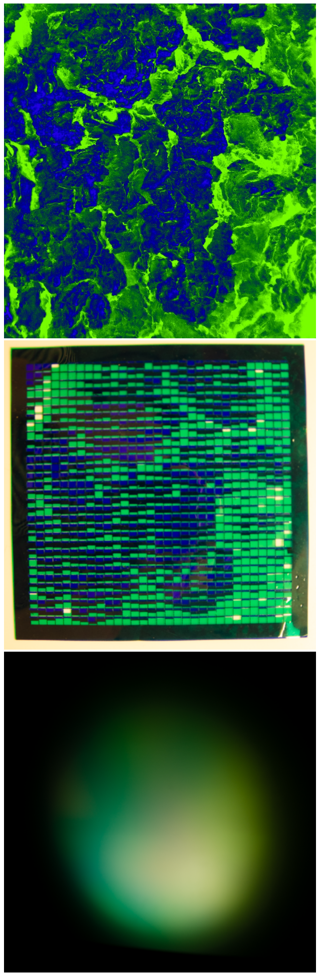

Figure 6: Top: A blue and green abstract design target image [a]. Middle: Layered gel of the above target image. Bottom: The lit result.

[a]Image Source: Charles Rondeau, CC0 Public Domain

it can produce lighting effects with much more complexity and detail than feasible by hand, enabling designers to achieve many lighting effects with a single fixture instead of three or four. Although our system does not match the detail produced by a glass gobo, the approach we describe can produce new iterations in about fifteen minutes with minimal cost ($1-2), opposed to weeks and hundreds of dollars. This approach also enables smooth color mixing which can be controlled freely by the designer.

The four examples shown (Figures 2-6) reflect a variety of situations in which our tool is useful. Figure 2 reveals our system's ability to smoothly mix colors. While a hand-cut solution (a green and blue gel taped together) could produce a small gradient (due to the natural scattering of the fixture's light), a hand-cut solution offers no further control over the length of the gradient's transition, while we enable designers to iterate on this shape. Figures 3 and 4 demonstrate a design which would be very difficult if not impossible to achieve with normal hand-cut solutions, a set of patterns which would be infeasible to cut without a laser cutter, and a fairly accurate lit result. Figure 5 demonstrates another effect which, like Figure 2, is well approximated by our method while also offering significantly more control than existing hand-cut solutions. Figure 6, which uses an unfiltered public domain image, reflects the current upper limit of detail in our system. While the lit result matches the color distribution of the target image, greater detail in the lit result is desired to faithfully reproduce it.

Physical Iteration in the Lighting Design Process

By enabling designers to directly see how their lighting effects physically interact with other complex objects—skin, fabric, glass—in an inexpensive, fast, and expressive way, this paper frames design tools for lighting design as a process of iterating with physical materials. In this way, lighting designers can better use physical materials as sites of exploration and development, instead of visualization and pre-programming environments alone. We argue that material iteration within a complex physical environment is a meaningful aspect of lighting design, alongside visualization and pre-programming. We envision our tool as supporting these material-centric workflows in lighting design, opening the space for future tools which enable designers to less often leave the physical space as the site of iteration.

Future Work and Conclusion

Several opportunities exist for expanding the capabilities of our system. While we currently only accommodate two colors because of the geometric simplicity in dividing the square cell for the gel ratios, expanding the algorithm to accommodate three color gels would enable designers to utilize the entire RGB color space. This could be achieved with a triangle shape, which could allow a three color interpolation of the triangle's area according to all three RGB channels. While support for a third color would enable greater color possibilities in a single fixture, we predict it will not substantially influence the patterns or shapes achievable with our method, due to the natural upper limit in detail achievable with layered gels. A third color might also require a larger cell size for adequate mixing, reducing the detail in the projected image. In addition, supporting arbitrary gel colors instead of simply red, green, or blue could produce more accurate colors or provide novel opportunities for color mixing.

The manual alignment process could also be improved, perhaps with reference holes in all gel layers which could be aligned visually or with a simple jig. In order to achieve lit images with greater detail we need a smaller grid size, but that trades off of ease of alignment—grid size could be a tunable parameter given the specific needs of a designer's physical environment. To evaluate our system, we plan on running a comparative study of lighting designers using our system versus their traditional workflows, as well as compare the lighting effects produced with our method against those produced with glass gobos or LED fixtures. We also plan on experimenting with different kinds of gels in a theatre environment in order to evaluate the longevity of our patterns cut on a range of brands and gel types.

We presented a novel method for iterative lighting design using low-cost gels and a single conventional fixture. We hope this work inspires further investigations of lighting design tools that foreground iteration in physical environments.

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