Optical Phase Plates as a Creative Media for Special Effects in Images

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1 ABSTRACT

A new paradigm and methods for special effects in images were recently proposed by artist and movie producer Steven Hylen. Based on these methods, images resembling paintings may be formed using optical phase plates. The role of the mathematical and optical properties of the phase plates is studied in the development of these new art forms. Results of custom software as well as ASAP simulations are presented.

2 INTRODUCTION

In the 1950's, the market for cameras pushed photographic technology toward the capture of high-resolution, low-grain, images in full color, for high-end photography and scientific discovery recording. While such discovery and development belongs to the 20th century, the 21st century may lead the way to an entire new paradigm for photography as an art form.[1] Certainly vivid images can be readily captured with today's photographic cameras. However, it is possible that the capability of cameras can be extended to capture other dimensions that go beyond realism as a replication of the physical world. Today's realism is defined as the perfect, ideal replication. Anything else is subjective, such as impressionism, expressionism, or abstractionism. The research question is whether optical technology, such as photography, can provide a medium to create new art forms.

The research presented in this paper focuses on the development of creative optical technologies for conceiving new art forms. Hardware technology is being designed, developed, and built based on the original idea of Steve Hylen,[2] that allows encoding of optical phase plates, also thought of in the group as optical textures, in images in order to generate special effects such as painterly effects. Two optical phase plates are shown as an example in Fig.1. The novelty of the approach is the fact that special effects are created real-time with no need for post processing of the image.

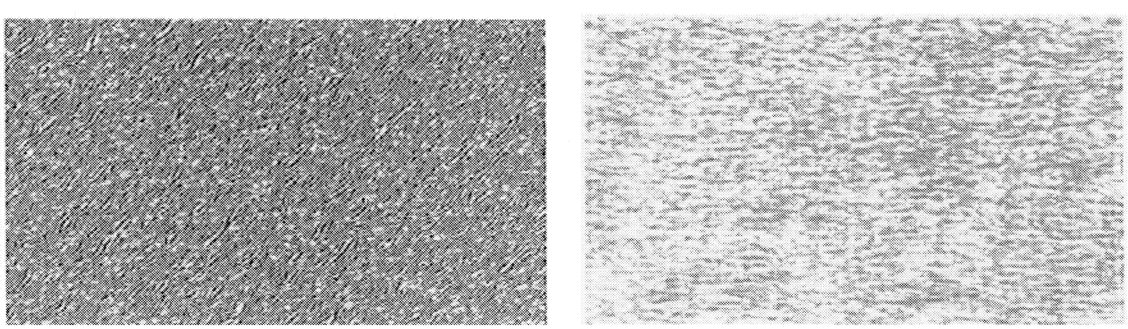

Figure 1. Example of optical textures

Novel Optical Systems Design and Optimization IV, Jose M. Sasian, Paul K. Manhart, Editors, Proceedings of SPIE Vol. 4442 (2001) © 2001 SPIE · 0277-786X/01/$15.00

3 EXPERIMENTAL SETUP

Conceptually the experimental setup uses an objective lens to form an image in an intermediary image plane, modifies the aerial image in this plane by using an optical phase plate and then optically relays the modified image on an image-capturing device (e.g. film or CCD) where the final image is recorded.

The experimental setup built consisted of a regular 50 mm Nikon objective used to form the intermediary image from a scene (e.g. a still life, a portrait, etc.) located in front of the objective. The location of the image produced by this objective was first measured experimentally for the given scene location. The optical phase plates that may be mathematically synthesized,[3,4] are micro fabricated using laser etching technology. The optical phase plate was located on a separate translation stage allowing for defocusing the optical phase plate with respect to the aerial image produced by the objective. The intermediary image itself could be defocused as well using the controls of the objective. Another objective was set as a 1:1 imaging system allowing relaying the intermediary image to the final image plane where a color CCD camera connected to a PC controlling the experiment was located. An actual photograph of the setup built is shown in Fig. 2.

Various final images as a function of the location of the optical phase plate and the defocus of the intermediary image were observed and recorded. Since there is no figure of merit suitable to evaluate how much the modified images resembled actual art forms, the selection was based on the experience of the people leading the experiment. It was established that the best results are produced when the optical phase plate and the intermediary image are both slightly (approximately 5mm) out of focus. However, the experimental setup was rather inconvenient to work with because it was fixed to the optical table and the image was not directly seen by the human eye. As a consequence the fixed setup led to difficulties in illuminating the scene and manipulating dynamically the defocus of the plate and the objective. Thus, a new design for the relay optics compatible with a standard 50 mm objective was conceived as a next step.

Parameter	Specification	Achieved
Source	Scattered Sunlight	
Detector	Standard 35mm film	
Field of view	Determined by the film size	Yes
F/number	F/7	Yes
Magnification	2	Yes
Effective focal length	Determined by the clearance to the film	Yes
Spectral range	From 400nm to 750nm	Yes
Image quality	MTF greater than 20% at 20lp/mm	Yes
Field curvature	TBD	As measured.
Vignetting	Pupil matching that minimizes vignetting	Yes
Overall length	Less than 100mm	85mm
Clearance to the film plane	Greater than 40mm	Yes
Clearance to the optical phase plate	Greater than 5mm	Yes
Prototype cost	Less than $15,000	$7,500

Table 1. Specification for the design of a relay lens to create optical art forms at the speed of light

The lens form for the relay optics was conceived in the Optical Diagnostics and Applications Laboratory (ODA Lab) in the School of Optics at UCF. The detailed design was done in close collaboration with Optical Research Associates.

There were two important conceptual ideas which determined the final design. First in order to make the design compact, a field lens was placed close to the last optical element of the standard 50 mm objective. As a consequence, the size of the intermediary aerial image decreased by a factor of 2. Therefore a modified 1:2 double Gauss lens was designed to relay the intermediary image to the final image location with a clearance of 40 mm to the last optical surface in order to account for the required clearance imposed by the body of the camera.

The second important conceptual idea was to be able to relay the exit pupil of the standard objective through the relay system in order to minimize vignetting. Various measurements of the exact location of the exit pupil for a standard 50 mm Nikon objective were thus performed. The specifications for the relay system are shown in Table 1 above. The MTF performance of the achieved relay system is shown in Fig. 3. The MTF holds well over the entire field of view.

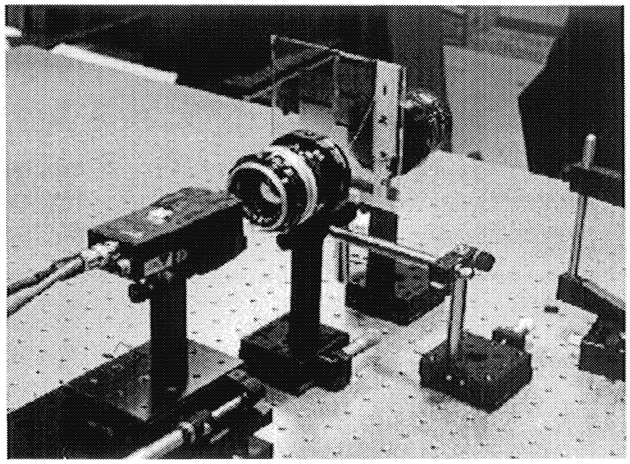

Figure 2. The experimental setup used to encode optical phase plates in images.

16 50:56

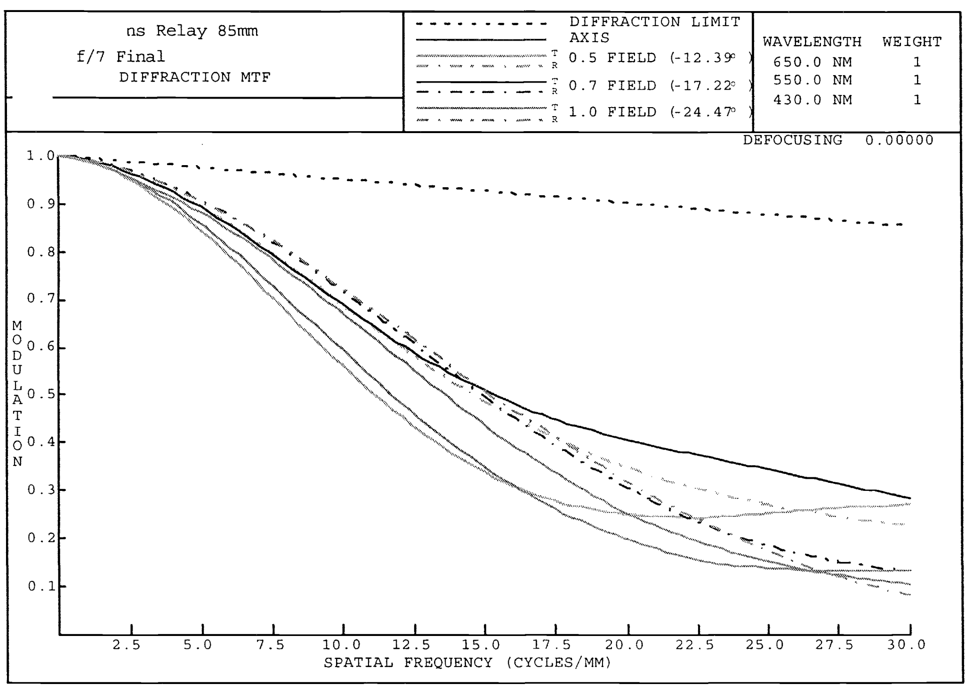

Figure 3. MTF Performance of the custom designed relay lens.

Based on the final design of the relay system a prototype was built. Using the prototype of the relay system together with a standard 50 mm Nikon objective and camera body, various results with various optical phase plates and amount of defocus were obtained. At this point the need for software predicting the visual appearance of an image modified with the hardware designed became apparent.

4 THEORETICAL MODELING

If an optical system were used to image specific scenes (e.g. still life, portraits, etc.), it would be intuitive for the user to be able to preview what the lens will accomplish on such a scene instead of relying simply on engineering figures of merit such as MTF, which will tell little if anything about special effects rendering. Thus, in the domain of special effects, we want as well to be able to predict precisely how images will appear to the human eye. Therefore, as part of this effort, modeling software is also being developed to predict physical outcomes obtained with the hardware. Approaches to modeling are based on optical raytracing, scalar diffraction theory and statistical optics. Until recently none of the existing optical engineering or lens design softwares were able to predict imaging through such systems due to the use of high resolution (i.e. 5μm pixel size) random optical textures in the optical path. The goals are not only to accurately model optical special effects, but also to attempt to do it efficiently.

The first approach consists in tracing rays from each point in object space through the entire system. Computationally, the object is considered self-luminous and a discrete version of the object is considered. Each pixel emits rays in blue, green and red colors in the amount respective to the gray level value that each pixel has in the respective color. Furthermore, the rays that are emitted from each pixel of the considered object propagate in air towards the entrance pupil of the optical system forming the final image. Upon encountering the first optical surface, the rays are refracted according to the Descartes' vectorial law of refraction.[5] For the imaging part through conventional optics, simple paraxial raytracing was used in the approach,[6] in order to first study the effect of the random phase plate alone. However, real raytracing through a real lens will be implemented in a later stage to fully predict the imaging through a designed lens with its own optical aberrations.

The most challenging task is to trace rays through the optical textures, as the ones shown in Fig.1, because they are fine in structure and rapidly varying, but also deep compared to the wavelength, in fact up to 25μm deep. In this approach (i.e. raytracing) to image formation, the local normal to any optical surface at the point where the ray intersects that surface must be computed, and in the case of the optical phase plate, it must be estimated. In the case of the optical phase plate, notions of smooth variations of the normal orientation and how to compute the normal comes into play. Moreover, to model mathematically the surface, a function that approximates the surface (such that the second derivative of this function is continuous) is needed. This imposes some severe restrictions over the way the optical phase plates are modeled. Physical optics modeling and statistical optics will aim at removing this requirement.

After raytracing through the optics and the plate, the final image must look like a typical image we obtain in hardware. Because of the limited number of ray samples and the discrete nature of the problem in the modeling computation, the Point Spread Function (PSF) of the optical system is considered as well. A component of the future work lies in defining mathematically point spread functions for such optical systems (i.e. conventional optical system with a "random" phase plate) and in comparing results to measured data. The PSF accounts for the finite size of the aperture of the optical system for in-focus imaging, given that for out-of-focus imaging it is negligible. Raytracing modeling in conjunction with a simple filtering final operation to account for the PSF does lead to encouraging results, yet the methods do not lead yet to accurate physical modeling of the optical imaging process under all imaging conditions. We have some good agreements for large-scale optical phase plates. This approach led to the development of in-house made raytracing software. Some typical results are presented in Fig. 4 and 5.

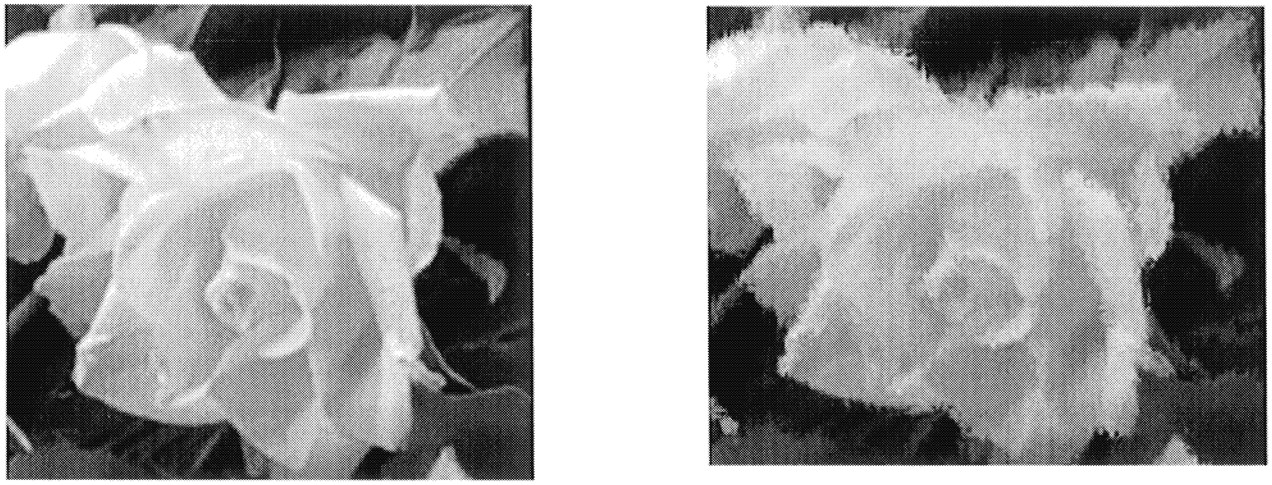

Figure 4. Painterly rendered yellow roses (right) and the original picture (left).

Figure 5. Painterly rendered picture of an old man (right) and the original picture (left).

Another part of the theoretical model and the software application developed is verifying the obtained results using ASAP, an optical modeling software from BRO Corporation. The software is used in conjunction with Rhinoceros (CAD software part of the ASAP Pro package). The main current limitation of ASAP is the number of the optical surfaces it is able to handle, which can not exceed 9,999. A mathematically synthesized optical phase plate might consist of as many as 24,000,000 surfaces. A way to overcome this limitation is to create the optical phase plate surface in a CAD program using another in-house made plug-in software and then export the surface into ASAP, where a real raytrace is performed. An example of an optical phase plate made of a mathematically synthesized bitmap source of 400 by 400 pixels and rendered in ASAP is shown in Fig. 6. A real raytrace and analysis of such a high number of optical surfaces has never been utilized before using ASAP. One of our preliminary raytracing results using ASAP and an optical phase plate is presented in Fig. 7, where ¼ of the image used as an object is covered with the optical phase plate shown in Fig.6. Although this approach requires more work on the scale of the optical phase plate and the pattern itself, this first result in ASAP seems to indicate that we can now use ASAP in conjunction with custom software and methods to further investigate rendering of painterly effects.

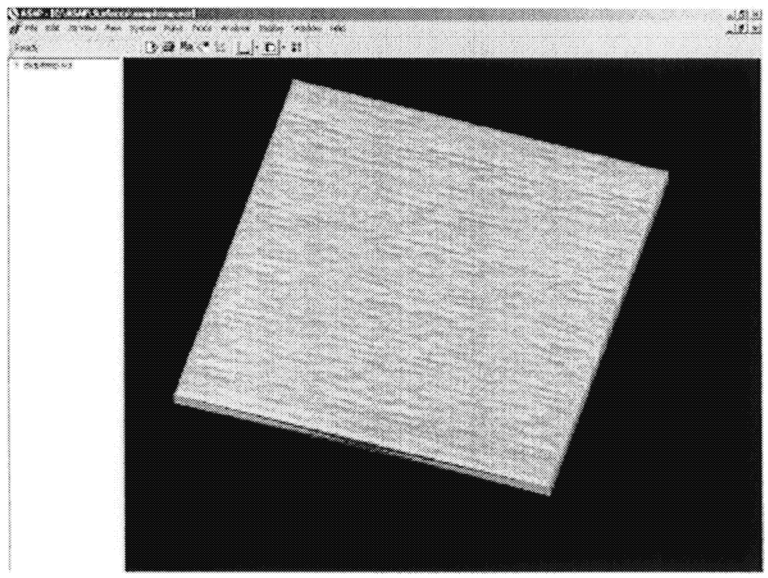

Figure 6. Optical phase plate rendered in ASAP.

Figure 7. Raytrace in ASAP using an optical phase plate covering the upper left ¼ of the object (right) and the original picture (left).

5 CONCLUSION

The research presented here led to the design and the development of a novel optical system consisting of a standard 50 mm Nikon objective and custom designed relay optics, allowing the photographer to create pictures resembling art forms such as painting at the speed of light. This unique application of photography allows photographers to perform real time image processing by changing the scene and the optical wave plate used as a function of their own artistic perception. This novel approach to photography inspired the development of a theoretical model and a custom designed software, which could itself be used for generating new art forms.

6 ACKNOWLEDGMENTS

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