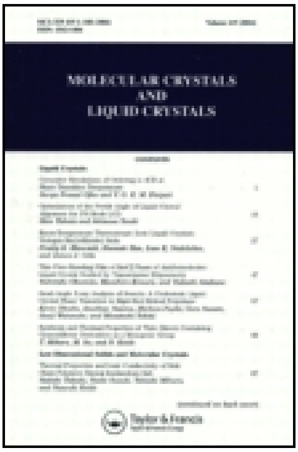

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Application of the Photochromic Adaptive Filter for All-Optical Image Processing and Its Characterization

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APPLICATION OF THE PHOTOCHROMIC ADAPTIVE FILTER FOR ALL-OPTICAL IMAGE PROCESSING AND ITS CHARACTERIZATION

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Abstract Several Photochromic Adaptive Filters (PAF's) made of organic photochromic materials embedded into a polymeric matrix are prepared. Transformation Function (TF) of the photochromic filter is determined using a simple, fast and accurate procedure. PAF's are used as opto-optic Spatial Light Modulators (SLM's) for image processing in the camera system, which unites a Charge-Coupled-Device (CCD) camera with a photochromic filter. Change in the local absorption of the filter, caused by light radiation, is used to enhance the quality of the detected image.

INTRODUCTION

In this paper, efforts to build one of the possible implementations of the adaptive filter[1], Photochromic Adaptive Filter, which utilizes photochromic material[2] embedded in a polymeric environment are described. The concept of extending the operating range of the constructed image-acquiring system by using optically-addressed PAF's is successfully tested[3]. Input image is transformed by a photochromic SLM to adjust output light intensity range to the dynamic range of the electronic detecting system. This system is also used to determine a Transformation Function of these filters using a new method.

MATERIALS

Stable photochromic filters, with high[4] photochrome concentration and good optical characteristics, consisting of a polymeric thin film with embedded photochromes, had been developed. After a series of tests using several of the most common polymers, one particular type of host matrix, Butyl Methyl Methacrylate Copolymer (B-725), was chosen, as it gave the most satisfactory results. The final version of Photochromic Adaptive Filters was prepared by a spin-coating technique using a solution of copolymer B-725 and photochromic substances in Butyl Cellosolve® and trichloroethylene[1]. All materials were of the highest grade available and were used without any further purification. Specific percentages of different photochromes were added to achieve custom transmittance through the visible region[5]. Compounds (**1-3**) were obtained from "*2nd Story Concepts*" Inc. Canton, OH. USA, compounds (**4-7**) were obtained from Aldrich Chemical USA:

6'-Piperidino-1,3,3-trimethylspiro[indoline-2,3'-[3H]naphth[2,1-b][1,4]oxazine (**1**), maximum absorption of the activated photochromic filter: $\lambda_{max} = 569$ nm.

3,3-Diphenyl-3H-naphtho[2,1-b]pyran (**2**), $\lambda_{max} = 423$ nm.

1,3,3,4,5,-Pentamethylspiro[indoline-2,3'-[3H]naphth[2,1-b][1,4]oxazine] (**3**), $\lambda_{max} = 609$ nm.

5-Chloro-1,3-dihydro-1,3,3-trimethylspiro[2H-indole-2,3'-[3H]naphth-[2,1-b][1,4]oxazine] (**4**), $\lambda_{max} = 600$ nm.

1,3-Dihydro-1,3,3-trimethylspiro[2H-indole-2,3'-[3H]naphth[2,1-b][1,4]oxazine] (**5**), $\lambda_{max} = 601$ nm.

5-Chloro-1,3-dihydro-1,3,3-trimethylspiro[2H-indole-2,3'-[3H]phenanthr-[9,10-b][1,4]oxazine (**6**), $\lambda_{max} = 580$ nm.

1,3-Dihydro-1,3,3-trimethylspiro[2H-indole-2,3'-[3H]phenanthr[9,10-b]-[1,4]oxazine] (**7**), $\lambda_{max} = 583$ nm.

Table 1 presents typical parameters of the solution and spinning procedure used to fabricate the final version (NN series) of the thin film filters using B-725 copolymer; these were later used for testing image transformation. High quality, flat glass sheet

TABLE I Typical photochrome-polymer solution formulation

	Polym. conc. C_{wt} [%]	Solvent conc. C_{wt} [%]	Phot. conc. C_{wt} [%]	Spinning conditions speed [rpm] : time[s]	Film Thickn. d [μm]
NN series	25.5	72	2.5	500 : 30	19.0

(110x110x2.3 mm)* was used as a substrate. Before polymer deposition, the glass was thoroughly cleaned and dried. Desired thickness of the filter was obtained by varying both the concentration of the copolymer and the conditions of the spinning process. The overall thickness of the layer may vary by 1-2 μm across the surface; however, the surface was free of local deformations.

EXPERIMENTAL SETUP

The test bench, utilizing a standard video camera and frame-grabber attached to the Sun work-station, is shown in Fig. 1[1,6]. The image was focused through a positive quartz lens on a thin photochromic filter placed on the glass substrate and the picture was recorded with the camera. Any high spatial resolution B/W camera with known relation between light intensity and output voltage (linear function being most common) can be used. In this work the 8 bit, 1810 series **COHU** camera was used. An Infra-Red Blocking (IRB) filter (Oriel IRB colored glass filter #59050), was used to reduce heating of the filter, which changes coloration. For each photochromic filter prepared, a specific interference filter or

* Agfa-Gevaert Millimask glass: n_D=1.51.

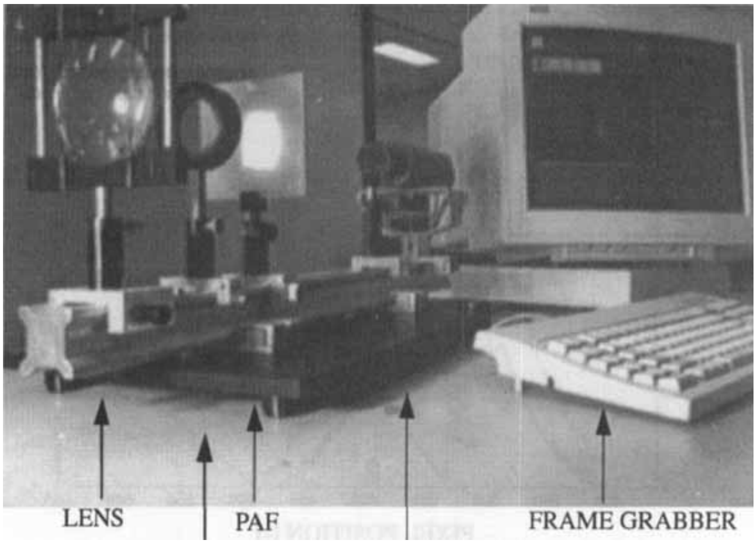

FIGURE 1 Photograph of the experimental set-up for testing photochromic filter (for clarity, housing of the light-tight chamber has been removed).

a broad-band color glass filter was used as a Modification (MOD) filter to restrict the analyzed spectrum to the region of sensitivity of the photochromic filter.

MEASUREMENTS

The spectral characteristics of different photochrome-polymeric matrix systems were measured with the Beckman DU® series 600 spectro-photometer. It is a single beam, high accuracy ($\Delta\lambda = 0.5$ nm), quick response time ($\Delta t = 0.05$ s) measuring system. Data collection rate is 20 samples/second. Using an Abbe Refractometer – Model 2WA, the refractive index for different coatings was measured. Film thickness was obtained with a profilometer (Dektak IIA Surface Profile Measuring System – by *"Sloan Technology"*).

Transformation Function was determined using a novel method. Fig. 2 shows the cross-section of a 3-D visualization of the lamp images. One curve shows the section of the image in the faded state. Another curve was taken from the lamp image after exposing the filter for 30 seconds to a 200W mercury lamp. Due to an adaptation of the filter the distribution of light intensity had changed and was lower when compared to an image obtained with a non-adapted filter. The transformation function, which relates the input and output light flux, was calculated and is shown in the inset. There are 160 measurement points in this inset. The transformation function does not start from the axis origin, due to optical losses and the threshold characteristic of the CCD camera. For average (0.1-1.9

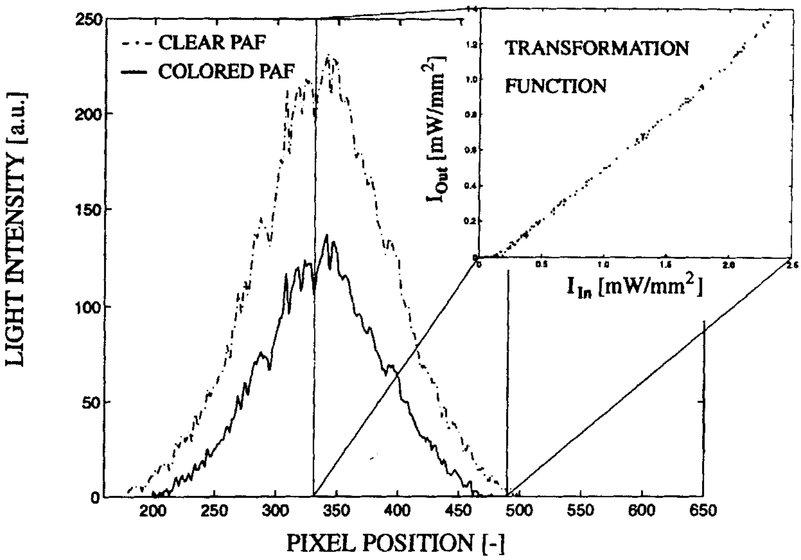

FIGURE 2 Cross section of the image of the light source; Transformation Function is plotted in the inset.

mW/mm^2) light intensities this function is linear, corresponding to a direct proportion between the number of activated molecules and the amount of light. For high light intensity a small deviation of the TF from linearity can be seen. This is a result of a limited supply of photochromic compounds in the filter[7] and increased thermal decolorization of the filter. Optical Density and the Transmittance of the photochromic filter as a function of light intensity can be calculated in a straightforward manner from the Transformation Function. The highest optical response value found was ΔOD=0.8.

RESULTS AND DISCUSSION

In the last section, an easily implemented method of characterizing the Transformation Function as a function of light intensity has been described[1,7]. The same method can be used to assess other properties of the thin film filter or the characteristics of the light sources. By comparing two series of measurements for the same photochromic system in different positions, non-uniformities in surface concentration of photochromes can be detected. This system can also be used for fast determination of spatial and spectral uniformity of the light sources with a UV spectral component. By analyzing two transformation functions for two different light sources, one can very quickly evaluate spectral and spatial non-uniformities of the light sources. For example, a short arc mercury lamp (HBO 200W) and a Sun-like lamp (300W) were used as light source. By comparing shape of curves in Figs. 3.a & 3.b, we see that lamp visualized in sub-figure b. has a very non-uniform component of UV spectrum in the high intensity region.

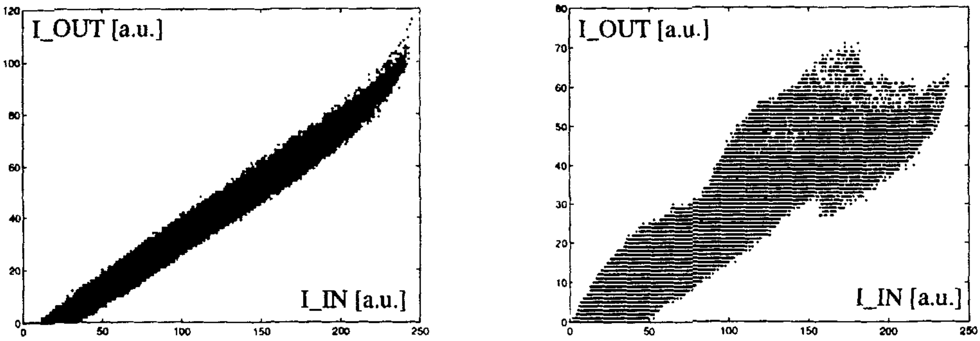

FIGURE 3 Transformation function for spectrally and spatially uniform a. and non-uniform b. light sources (300,000 measurement points).

Next, experiments testing photochromic filters in the local adaptation mode[8] were performed. In one experiment a picture was taken of two different light sources – a mercury arc lamp and a halogen lamp, varying in light intensity over 1 decade (Figs. 4.a & 4.b*).

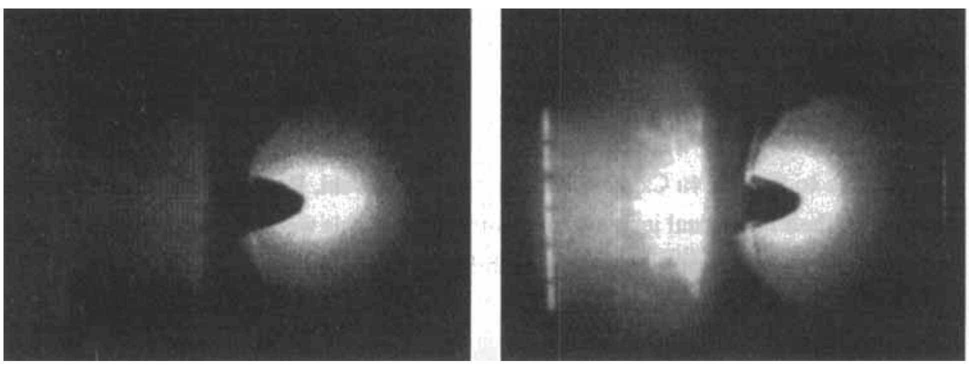

FIGURE 4 Image quality improvement. Before a. and after b. local adaptation: photochrome (**2**) in B-725 matrix, interference MOD filter – 420 nm.

The image of the more intense mercury arc lamp (Fig. 4.a, on the right), nearly saturated the camera. With time, the focused image of the high intensity mercury lamp locally decreased the transmittance of the filter, due to the UV radiation emitted by this lamp. The intensity of the image of the second lamp stayed at the same level, as this lamp's image does not cause any changes to the filter. At that point the diaphragm of the camera was opened wider and one more picture was taken. This procedure corresponds to the image

* Color version of the original pictures can be found at: http://fas.sfu.ca/ensc/people/GradStudents/tomasz/personal/tomasz.html.

normalization, to match the image with the operating range of the camera. By comparing Figs. 4a & 4b, the conclusion can be drawn that image was transformed by the PAF in such a way, that only part of the spatial distribution of image light intensity was compressed – local adaptation of the PAF occurs. As a result of the local adaptation process, a picture that contains more visible details of the other part of the image was obtained. Both lamps are clearly visible, and at the same time no part of the picture is oversaturated; thus negative effects like blooming are suppressed.

CONCLUSION

In this paper, a research project leading to the development and applications of Photochromic Adaptive Filters has been described. A series of thin films made of polymers and photochromic materials were designed and fabricated. The developed filters were successfully applied in an opto-electronic system which united a CCD camera with a photochromic filter to create an adaptive camera. Although the transition time was relatively long in modern electronic terms, this system was capable of operating over a wider range of light intensities[9]. By using the adaptive filter the dynamic range of operation was extended, and as a result contrast ratio was increased and both blooming[10] and flare were minimized.

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