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APPLICATION OF OPTICAL IMAGE PROCESSING TECHNIQUES TO ACPL EXPERIMENTS

ABSTRACT

A few state-of-the-art optical image processing techniques are described and their potential applications to the ACPL experiments are suggested. The discussion also includes the selection of recording media in the present system and the enhancement of signal-to-noise ratio for the expected data from ACPL.

APPLICATION OF OPTICAL IMAGE PROCESSING TECHNIQUES TO ACPL EXPERIMENTS

I. Introduction

In the experiments planned for ACPL, the data expected will be in the form of photographs. Aerosol density and particle sizing measurements usually yield poor pictures, partially due to the limitations of the photographic system with respect to the recording of the Mie scattering light from micron size particles. This report will briefly describe a few latest developed techniques in optical image processing that are applicable to the enhancement of the expected ACPL data. The techniques include coherent optical equidensity and pseudocoloring of pictures as well as optical analog-to-digital conversion.

In addition, photographic films that are thought to be most appropriate for recording the existing ACPL optical system are recommended.

II. Optical Image Processing Techniques

A. Equidensity and pseudocoloring by coherent optical filtering using a single halftone photograph.

The halftone screen method can be used to produce contours of contours of constant brightness on a continuous tone photograph, the first step is to produce a halftone photograph of the original object. This can be done by simply contact printing the photograph through the halftone screen on a high-γ (high contrast) copying film. An incoherent light source that has an average power density ρ on the film plane is used. The exposure of the film for a time interval τ produces an exposure defined by

$$E(x,y) = \rho\tau 10^{[-D(x)-D_p(x,y)]} \ , \qquad (1)$$

where $D(x)$ and $D_p(x,y)$ are the density distributions of the halftone screen and the continuous tone photograph, respectively.

The copying film has a threshold level E_t such that after the development of the exposed film the transmittance of the film will be a binarytype function. Assuming that the γ of the film is very large, the transmittance of film may be written as

$$T(x,y) = 1, \quad E(x,y) < E_t, \quad E(x,y) \geq E_t \ . \qquad (2)$$

The above equation indicates that the original continuous-tone photograph is converted to a spatially modulated binary photograph. The modulated photograph of the original object is called the halftone photograph.

By control of the exposure level, $\rho\tau$ in Eq. (1), a variety of mappings of picture density into halftone linewidths can be achieved. The maximum number of different widths in any halftone photograph cannot be greater than the number of gray levels of the halftone screen.

The halftone photograph is then placed in the input plane of a coherent optical data processing system. If the wavelength and geometrical factors are omitted for clarity, the nth-order output intensity at the Fourier plane is

$$I_n\left(\frac{b}{a}\right) = \left(\frac{1}{n\pi}\sin\frac{n\pi b}{a}\right)^2 \ , \qquad (3)$$

and the normalized nth order output may be written as

$$\overline{I}_n\left(\frac{b}{a}\right) = n^2\pi^2 I_n\left(\frac{b}{a}\right) = \sin^2\frac{n\pi b}{a} \ , \qquad (4)$$

where $n \geq 1$, and b is the width of the opaque lines $b/a \leq 1$. The zero order output may be written as

$$I_0 = \left(1 - \frac{b}{a}\right)^2 \ . \qquad (5)$$

Equations (3), (4), and (5) are derived using the assumption that an infinite number of periodic opaque lines of width b and period a are in the object plane. In reality, if a sufficiently large number of the opaque lines exist in a certain area, these equations may be considered as good approximations so that no aliasing phenomenon should prevail.

Equation (3) indicates that there are at most n equal maxima and n equal minima in the nth order output, hence it will take a halftone mask with at least 2n equal-width gray levels to produce a halftone picture (of a photograph) that will yield a maximum of n bright contour lines. For the same halftone picture, other diffraction orders also generate contours of constant brightness, but these contours generally correspond to different brightness levels.

Pseudocoloring of a photograph can be achieved as follows. In the coherent optical system, lasers of the three primary colors, blue (B), green (G), and red (R), are used, with their wavelengths respectively denoted by λ_B, λ_G, and λ_R, and collimated beam intensities expressed by I_B, I_G, and I_R. For each color, any desired diffraction order may be selected, and the three resulting color images can be recorded on a color film, or displayed simultaneously on a screen or by means of a color television monitor. If l, m, and n denote the selected diffraction orders, the total intensity at a particular location of the output image, corresponding to the region where periodic opaque bars of width (a-b) are found in the half-tone photograph, may be given by

$$
\begin{aligned}
I_T = &\left\{ \frac{I_B a^2}{\lambda_B^2 f^2} \frac{1}{l^2 \pi^2} \sin^2 \frac{l \pi b}{a} \right\} + \\
&+ \left\{ \frac{I_G a^2}{\lambda_G^2 f^2} \frac{1}{m^2 \pi^2} \sin^2 \frac{m \pi b}{a} \right\} \\
&+ \left\{ \frac{I_R a^2}{\lambda_R^2 f^2} \frac{1}{n^2 \pi^2} \sin^2 \frac{n \pi b}{a} \right\} \\
= &\{I_{Bl}\} + \{I_{Gm}\} + \{I_{Rn}\} , \qquad (6)
\end{aligned}
$$

where

$$I_{B1} \equiv \frac{I_B}{\lambda_B^2 f^2} \frac{a^2}{1^2 \pi^2} \sin^2 \frac{1\pi b}{a} \quad , \qquad (7)$$

$$I_{Gm} \equiv \frac{I_G}{\lambda_G^2 f^2} \frac{a^2}{m^2 \pi^2} \sin^2 \frac{m\pi b}{a} \quad , \qquad (8)$$

and

$$I_{Rn} \quad \frac{I_R}{\lambda^2 f^2} \frac{a^2}{n^2 \pi^2} \sin^2 \frac{n\pi b}{a} \quad . \qquad (9)$$

The net color, as a result of the mixture of these primaries, can be determined from a CIE chromaticity diagram. Naturally, the mixing of the three primaries does not have to be united to the one-color-one-order assignment as even in Eq. (6). Any number of diffraction orders may be assigned to any color and different laser intensities may also be easily controlled by an attenuator. These features show that the new pseudocolor encoder has considerable flexibility.

B. A new and direct optical analog-to-digital conversion method.

The A-D conversion screen

The new method basically involves the design of an analog-to-digital conversion screen. The screen can have a periodic array of identical cells each of which has a transmittance function being designed for a specific A-D conversion requirement. The screen can either be two-dimensional or one-dimensional depending on the practical applications. A simple example, without loss of generality, can be presented with the help of Figure 1. In the Figure, T_1, T_2, T_3, and T_4 represents the intensity transmittances of a unit-cell (of 2a x 2b) of a two-dimensional A-D conversion screen. The transmittance function of this unit-cell may be mathematically expressed by

$$\begin{aligned} T_u(x,y) = {} & T_1\,[u(x) - u(x-a)]\,[u(y) - u(y-b)] \\ & + T_2\,[u(x+a) - u(x)]\,[u(y) - u(y-b)] \\ & + T_3\,[u(x+a) - u(x)]\,[u(y+b) - u(y)] \\ & + T_4\,[u(x) - u(x-a)]\,[u(y+b) - u(y)] \ , \end{aligned} \qquad (10)$$

where u(.) is the well-known unit-step function defined by

$$u(x) = 1 \quad x \geq 0 \ ,$$
$$= 0 \quad x < 0 \ . \qquad (11)$$

If the A-D conversion screen is made of the unit cells that are arranged periodically along the x- and y-direction with periods 2a and 2b respectively, and the dimension of the screen along the x-direction is $X = 4n_1a$, and $Y = 4n_2b$, where n_1 and n_2 are positive integers greater than 1, the transmittance function for the whole screen can be expressed by

$$T(x,y) = [T_u(x,y)] \star [\sum_{i=-n_1}^{n_1} \delta(x-i2a)] \star [\sum_{j=-n_2}^{n_2} \delta(y-j2b)] \ , \qquad (12)$$

where the symbol "*" denotes the convolution operation and $\delta(x)$ is the delta-function defined by

$$\delta(x) = 1 \ , \ x = 0 \ ,$$
$$= 0 \ , \ x \neq 0 \ . \qquad (13)$$

The use of the A-D conversion screen in a real-time A-D conversion system

The analog input signal, which could be a photographic transparency illuminated by uniform and collimated light (coherent or incoherent) is parallelly applied to the A-D conversion screen. An array of detectors, such as CCD devices, may be placed also in close contact next to the A-D conversion screen. Each MOS capacitor of the CCD should be alligned with each individual compartment that is distinguished by its transmittance in the unit cell of the conversion screen.

Because the physical size of the input image and the spatial resolution of the detectors can be different, flexible variations of the basic configuration can be made to accommodate the practical needs in each specific system, e.g., lenses can be used to magnify or demagnify the image at any stage in the A-D conversion process.

III. Selection of Recording Media

A. For particle counting purposes, we suggest the use of a high contrast film, such as the Kodak Kodalith 2568 pan film. The film is very fast and hence is good for the recording of the Mie scattering data.

B. For particle sizing and ice crystal formation purposes, high resolution film is suggested. Laser holographic technique is also recommended. For holographic interferometry, we recommend AGFA10E56, Kodak 649F or SO424 for argon laser; SO173/120 or SO253 for He-Ne and Krypton laser, and AGFA10E75 for Ruby laser. For laser data recording purpose, one should use HRP II cr SO424 for argon laser; and 8E75 for ruby laser. And finally, for spatial filtering operation, Lindgraph Shellburst should be used for all the lasers mentioned above.

The details of the characteristics are available from Kodak or AGFA Information Book.