DEVELOPMENT

OF A

VARIABLE GAMMA-PRODUCT REVERSAL PROCESSING SYSTEM

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Summary

A technique for detecting small changes between two photographs of a similar scene requires control of the gamma-product produced in the black and white reversal processing system*. It was desirable to have gamma-products of 0.5, 1.0 and 2.0, thereby allowing the illumination difference to be represented as the square root, linear or square of the original scene illumination. Variable gamma-products afford control to the experimenter for enhancing the scene differences. A further requirement of the processing system was maximum scale (long straight-line portion of D log E curve) and minimum toe and shoulder. The scale of the negative and positive subsequently produced by the reversal system should be of equal magnitudes to insure complete transfer of original scene information.

The processing system used for accomplishing these black and white reversal characteristics is not unconventional. The formulations are designed to provide gamma-product control by time and

* 'A Photographic Technique for Change Detection' [redacted] [redacted]

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temperature processing of the negative image followed by a completion developer fixing solution. Selection of the appropriate time and temperature for the first developer in combination with the appropriate second developer-fixer solution determines the gamma-product to be obtained.

Our work has employed Kodak Plus-X 35mm film for the developer formulation studies. The first developer is a low-gamma phenidone-hydroquinone formulation with a small amount of silver halide solvent included to control layer capacity and gamma. The film is processed in a first developer which is followed by a stop bath and washing; after which the negative may be fixed normally or bleached in an acidic potassium dichromate solution. After washing, which follows the bleach solution, the film is immersed in a clearing bath. The clearing bath removes the soluble silver salts and prepares the emulsion layer for subsequent development and fixation. Re-exposure may be effected by room light or by an organic fogging agent, such as t-butylamine borane, which is compounded in the clearing bath solution.

Depending upon the gamma-product desired one of three second developer formulations is used and processed for one time and temperature. Using a completion second developer-fix relieves the necessity for strict control of processing after the first development step has been completed. Chemical treatment effected in the clearing bath insures maximum scale, of the same magnitude as the negative images, in addition to controlling the base + fog of the positive image.

A PHOTOGRAPHIC TECHNIQUE FOR CHANGE DETECTION

Summary

The photographic process lends itself readily to the problem of detecting small changes or differences in two photographic records of a scene. When two successive photographs of the same general scene are taken sequentially (with a finite time interval between), it is possible to isolate small, low-contrast differences. The technique is limited to the linear portion of the material's characteristic curve, and depends on experimental adjustment of the processing and illumination constants.

Before establishing the necessary analytical relations, it will be essential to develop some preliminary ideas. These are the basic relations which exist between the photographic exposure and its resultant transmittance, irrespective of transfer function.

Preliminary Considerations:

1) The non-linear relation between exposure and transmittance is

$$T(\bar{x}) = a\,[E(\bar{x})]^{-\gamma}.$$

2) The proportionality between exposure and transmittance with two-step (or reversal) processing, is

$$T(\bar{x}) = b\,[E(\bar{x})]^{\gamma_1 \gamma_2} ,$$

and when

$$\gamma_1 \gamma_2 = 1 ,$$

the relation is linear.

3) Linear transmittance variations can be eliminated through trans-illumination of a superimposed negative/positive transparency pair, the necessary condition for which is that the gamma of the second process must be unity.

4) An exposure can be described in terms of its "ac" and "dc" parts:

$$E(\bar{x}) = p + q(\bar{x}) \ ,$$

and the resulting transmittance in these terms is

$$T(\bar{x}) = a_1 p^{-\gamma} \left[1 + \frac{q(\bar{x})}{p}\right]^{-\gamma}$$

$$\cong a_1 p^{-\gamma} \left[1 - \frac{\gamma}{p} \quad q(\bar{x})\right] \quad ,$$

for a low-contrast scene. The average transmittance is then given by

$$\overline{T(\bar{x})} = a_1 p^{-\gamma} \ .$$

5) Linear transmittance variations can be eliminated by simultaneous projection of a negative/positive transparency pair, so that their screened images are in register. Both illumination systems can be adjusted in brightness (b_1 and b_2), so that for

$$T_{12}(\bar{x}) = \text{constant},$$

$$\gamma_2 = \left(\frac{b_1}{b_2}\right) \left[\frac{\overline{T_1(\bar{x})}}{\overline{T_2(\bar{x})}}\right] \ .$$

or

$$\left(\frac{b_1}{b_2}\right) = \gamma_2 \left[\frac{\overline{T_2(\bar{x})}}{\overline{T_1(\bar{x})}}\right]$$

Change Detection:

The technique of change detection can now be developed. We consider two photographic transparencies of the same scene, taken with a finite time lapse between them. We must use a positive for one of them. The transparencies are characterized by

$$T_1(\bar{x}) = a_1 \ [E_1(\bar{x})]^{-\gamma_1} \ ; \ \ T_3(\bar{x}) = a_3 \ [E_2(\bar{x})]^{\gamma_2 \gamma_3} \ .$$

For this pair, using $E_j(\bar{x}) = p_j + q_j(\bar{x})$, and the low-contrast approximation

$$\overline{T_1(\bar{x})} = a_1 p_1^{-\gamma_1} \; ; \; \overline{T_3(\bar{x})} = a_3 p_2^{\gamma_2 \gamma_3}$$

We confine the small change to be detected to the "ac" portion of the signal, and will locate it in the second transparency. Thus,

$$q_2(\bar{x}) \approx q_1(\bar{x}) + \epsilon(\bar{x})$$

where

$$\epsilon(\bar{x}) << q_1(\bar{x}) \; .$$

The dissimilarities existing between the two transparencies by virtue of their having been modified by different modulation transfer functions will be assumed small, and of no significance for these considerations.

When the transparencies are superimposed, in register,

$$T_{13}(x) = \left[\overline{T_1(\bar{x})}\;\overline{T_3(\bar{x})}\right]$$

$$\cdot \left[1 - \left(\frac{\gamma_1}{p_1} - \frac{\gamma_2\gamma_3}{p_2}\right) q_1(\bar{x}) + \frac{\gamma_2\gamma_3}{p_2}\;\epsilon(\bar{x}) - \frac{\gamma_1\gamma_2\gamma_3}{p_1 p_2}\;q_1(\bar{x})\,\epsilon(\bar{x}) - \frac{\gamma_1\gamma_2\gamma_3}{p_1 p_2}\;q_1^{\,2}(\bar{x})\right]$$

The linear term in $q_1(\bar{x})$ vanishes when

$$\frac{\gamma_1}{p_1} = \frac{\gamma_2\gamma_3}{p_2} \; .$$

Since the two-step (or reversal) processing of $T_3(\bar{x})$ permits exposure adjustment so that p_1 can be made equal to p_2, the necessary processing conditions are

$$\gamma_1 = \gamma_2\gamma_3 \; .$$

The cross-product vanishes by an order-of-magnitude argument. However, the quadratic version of the original scene is still present, and the change, being small, could easily be hidden in this noise.

If the two transparencies are now projected (separately, but simultaneously), so that their screened images are in register, and with brightness b_1 and b_2, the resultant image will be proportional to

$$T_{13}(\bar{x}) = b_1 T_1(\bar{x}) + b_2 T_3(\bar{x}) \quad .$$

When we employ the low-contrast approximation,

$$T_{13}(\bar{x}) = \left[b\, \overline{T_1(\bar{x})} + b_2\, \overline{T_3(\bar{x})} \right] + b_2\, \overline{T_3(\bar{x})}\, \frac{\gamma_2 \gamma_3}{p_2}\, \varepsilon(\bar{x}) + \left[b_2\, \overline{T_3(\bar{x})}\, \frac{\gamma_2 \gamma_3}{p_2} - \frac{b_1 \gamma_1}{p_1}\, \overline{T_1(\bar{x})} \right] q_1(\bar{x}) \quad .$$

The necessary condition that the scene information vanish and leave only the change is

$$b_2 \frac{\gamma_2 \gamma_3}{p_2}\, \overline{T_3(\bar{x})} = b_1 \frac{\gamma_1}{p_1}\, \overline{T_1(\bar{x})}$$

or

$$\gamma_2 \gamma_3 = \gamma_1 \left[\frac{T_1(x)}{T_3(x)} \right] \cdot \left[\frac{p_2}{p_1} \right] \left[\frac{b_1}{b_2} \right] \quad .$$

Now the coefficient of γ_1 contains only constants, two of which (b_1 and b_2) can be continuously adjusted in the projection step. Thus, by varying the relative illumination strength of the two projection systems, the value of the coefficient can be made equal to unity, and

$$\gamma_1 = \gamma_2 \gamma_3$$

as before, or

$$\left[\frac{b_1}{b_2} \right] = \left[\frac{\overline{T_2(\bar{x})}}{\overline{T_1(\bar{x})}} \right] \left[\frac{p_1}{p_2} \right] \left[\frac{\gamma_2 \gamma_3}{\gamma_1} \right] \quad .$$

Then

$$T_{13}(\bar{x}) = b_1 \overline{T_1(\bar{x})} + b_2 \overline{T_3(\bar{x})} + b_2 \overline{T_3(\bar{x})} \frac{\gamma_1}{p_2} \varepsilon(\bar{x}) = C \left[1 + \frac{\gamma_1}{2p_2} \varepsilon(\bar{x}) \right] .$$

Thus, the original scene illuminance distribution has been eliminated, and the projection image now contains only the differences. The information exists at extremely low contrast, and must be amplified through subsequent high-gamma printing, or by image intensification techniques. The key to the change detection process is control of the processing constants, the gammas, and the adjustment of the projection beam projection brightnesses. There is a trade-off between processing constants and beam brightnesses which eases the requirement for extreme precision on the gamma-product. On the other hand, it is best not to have the beams differ too much in brightness for reasons of relative visibility. Since the photographic constants can be easily controlled, precision on the gamma-product can be routinely obtained through a reversal system. Then the light-balancing constitutes only a small, final correction to compensate for the variation in average transmittances.