Variability of Medical X-ray Film

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Abstract

This work has the aim of establishing that silver halide based films are subject to variation in response due to the uncertainty principle since the size of the detector used namely the silver halide grain is very small. This phase leads to the identification of parameters in film building that can reduce variability, and subsequently to the manufacture and use of such films leading to greater diagnostic reliability. The work will establish the variability due to experimental parameters such as fluctuations in illuminance, time and intensity of exposure, temperature and pH of processing, coating thickness. This will permit the evaluation of intrinsic variability arising from the uncertainty principle. Since different manufacturers use a variety of emulsion characteristics, information will be collected on a number of commercial products. Further work will focus on studies with films that are specifically designed and manufactured to reduce variability.

Introduction

Since the ideas of Hurter and Driffield are not consistent with current understanding of photographic sensitometry (Gokhale(1994, 1995, 1996, 1997))[1,2,3,4], I propose to develop a complete theory of photographic sensitometry including aperture, illumination and densitometry. However in order to gain acceptance for my ideas experimental information about one practical product is needed. I propose to study medical X-ray since variability is a matter of diagnostic concern. New type of sensitometric data viz. the variation in exposure required to reach a given density for a number of commercial products, will be gathered. This variation will be interpreted in terms of the uncertainty principle and its dependence on wavelength of exposure and grain size and shape explained. The Heisenberg uncertainty principle is applicable, since when a grain is rendered developable the position of the absorbed photons is fixed to within the volume occupied by the grain. This limitation on the position uncertainty induces a corresponding lower bound on the momentum and energy uncertainties. The result in terms of the exposure uncertainty is

$$\Delta E/E \geq \lambda/(2\pi \Delta x)$$

Since photons are detected in grains their position gets specified. Position and momentum are conjugate variables so they cannot be specified with arbitrary precision. Thus $\Delta x \, \Delta p_x \geq h/(2\pi)$. For light $\Delta p_x \leq \Delta E/c$ and $h = \lambda E/c$ which leads to the above result. It should be emphasized that the result holds for any number of photons detected on a patch of any size irrespective of the number of grains present.

At 450 nm, with a grain size of 0.4 micron $\Delta E/E \geq 0.1$. This is a significantly high lower bound which would warrant measurement of the actual contribution due to uncertainty. This large uncertainty in light exposure would correspond to density uncertainties at least larger than 0.2 which are easily capable of causing loss of clinical information. Thus, while prior understanding would suggest that simply making grains small will reduce variability and granularity, application of the uncertainty principle would suggest that when the grain size is close to the lower limit (see e.g. Gokhale(1996)[3])

$$\Delta x \geq \lambda/(2\pi)$$

where Δx is the smallest dimension of a rectangular box that would hold the grain and λ is the wavelength of the exposing radiation, the noise in the response will become very large.

By identifying the important factors in controlling film variability, it will be possible to proceed with film manufacturing as well as providing a marketing tool for the company's unique film structure. The Phase 2 project will focus on manufacturing film with the least amount of variability. The variability estimates for different films will also ensure that various latent image intensification techniques will produce results within current variability limits. These techniques will enable exposure reduction and improve quality..

Phase 1 Research Objectives

The principal objective of the Phase 1 research is to establish lower bounds on the variability of response of medical x-ray film due to inherent uncertainty and establish

a baseline for overall variability so modifications to current technology can be evaluated in terms of their effect on response.

Research Plan

X-ray films used in screen-film systems utilize different regions of the visible and ultra-violet region depending on the type of phosphor used and its emission characteristics. ISO standards are available that specify the exposure time and illumination conditions appropriate for two general classes of films viz. blue sensitive and green sensitive. The illumination source is tungsten at a specified color temperature. The filters suggested are broad band filters. Since the purpose of the proposed research is to demonstrate variability and the effect of film building parameters on it, wide band blue and green filters will be chosen to simulate blue and green emitting phosphors. To demonstrate the magnitude of the variability intrinsic to the film it will not be necessary to reproduce the ISO standard conditions. Blue and green filter combinations used in color enlargers in a color processing facility will be used for the purpose of this research. The illumination source will be the one available in the enlarger/s. Stability and uniformity of illumination will be measured photometrically. Specifically, a United Detector Technologies photometer will be used to measure illuminance at the film plane. Non-uniformity of illuminance at the film plane will be measured by regular surveys to calculate the standard deviation. Standard exposure times of 0.1 second will be used since they can be produced with precision. Variability in the shutter will be estimated by capturing the transient photometric signal and calculating its standard deviation. A single exposure target consisting of a step tablet will be used. To eliminate issues of registering, a single one-sided exposure will be used for each sheet measured.

Film development will be carried out in using the development cycle and chemicals recommended by each manufacturer. While hand processing may not be the mode used currently, it will suffice since the aim of the current work is to bound the relative contributions from processing and intrinsic variability. Densitometry will be carried out on the processed film using an X-rite densitometer. "Visual" (i.e. approximately green as specified by ISO standards) density filters will be used in the densitometer. The resulting densities will be entered into a database with corresponding exposures. The mean exposure required to reach a density of 1.0 for each sample will be estimated and the standard deviation will be recorded. Since the standard deviation in exposure due to illumination will be known it will be possible to estimate the standard deviation in exposure required to reach a density of 1.0. Standard deviation in exposure due to densitometry, will be eliminated from the estimate by performing repeated measurements on identical samples The new estimate will also contain the standard deviation in exposure due to processing variations.

The errors in measured quantities will be reported in the standard way specified by the center for weights and measures. The standard deviation in exposure due to chemical mix change will be bounded also by estimating the maximum change due to change of mix by using several batches of chemicals. Standard deviation in exposure due to processing variations will be estimated by measuring the variation in temperature and pH during processing and subsequently recording the change in the measured response (viz. mean exposure required to reach a density of 1.0) due to deliberately applied changes in development temperature and pH. This will permit the extraction of the desired value of standard deviation of exposure without any other significant effects other than film building parameters such as grain size, shape region of sensitization. Manufacturing variations such as coating will be bounded by using the same batch of film and the fact that film thickness variations are bounded by manufacturing specifications, unlike the variability introduced by the uncertainty principle as discussed earlier.

The above discussion may be summarized in the following equation:

$$\sigma_{total}^2 = \sigma_{uncertainty}^2 + \sigma_{processing}^2 + \sigma_{exposure}^2 + \sigma_{manufacturing}^2$$

where each term is the variance in the measured response due to the subscripted cause. Once, upper bounds are established for the last three factors, and the total variance measured, it will be possible to estimate the lower bound for $\sigma_{uncertainty}^2$.

As large a sample size from each manufacturer will be used as is possible within the funding limits and the variability and film data tabulated in the database for general use. Since the standard deviation in the estimate is proportional to $1/\sqrt{}$ (sample size), it is estimated that several thousand samples will need to be measured for each product.

To elucidate the different results obtained from the approach adopted in the current work as compared to prior work, consider Figures 1 and 2. Figure 1 shows the type of response curve known as the Hurter and Driffield curve which shows the variation of density with exposure. There is no indication that there is variation in the density attained in spite of maintaining processing and other variables within controlled limits. Whereas Figure 2 shows the type of response curve that will be obtained as a result of the proposed work. This information can be used to assess quantitatively chances of failure of the radiographic method. It can be used to decide which films will improve chances for success and the conditions for using them.

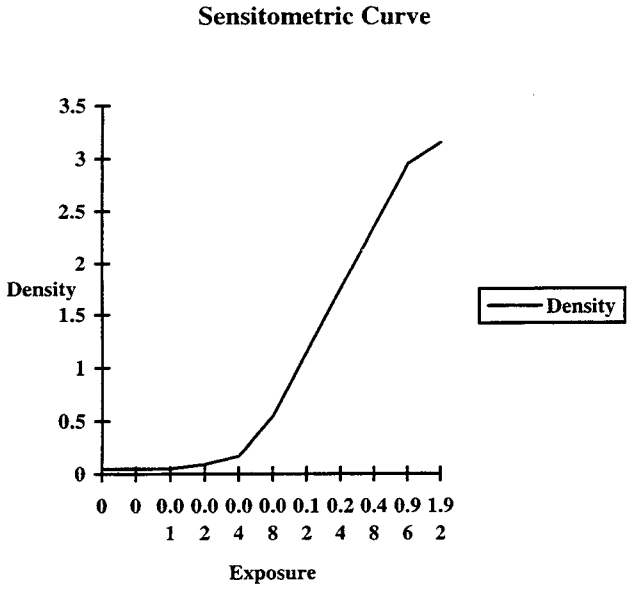

Figure 1: Response Curve Obtained Currently

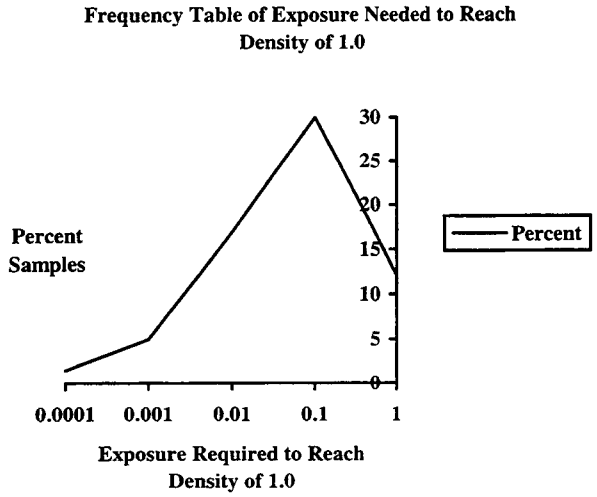

Figure 2: Response Curve Obtained by Proposed Research

References

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