

Forty Years with Hardcopy Noises

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Abstract

Following the 40 year career as an imaging engineer, various imaging systems are compared and characterized from the viewpoint of noise. The concept of geometrical noise is described and its significance is proved by the history of non-silver X-ray recording. Some image quality metrics based on the amount of colorant or photo-sensor are explained. Finally, issues in digital ages are dealt with.

INTRODUCTION

Today's talk will deal with a few issues relating to hardcopy noises that I encountered in my career as an imaging engineer since 1957.

I was most deeply involved in the R&D of electrophotography including Carlson and electrolytic process, particle migration, photo-electrophoresis, etc.

Though some of my efforts succeeded commercially, all the trials of tone re-production by analog electrophotography ended with failure, which experience led me to compare electrophotography with AgX photography. In this comparison, learning much from R. Shaw[1] and A. Rose[2], I became convinced of the significance of noise not only for image quality but other properties such as imaging speed, etc.

CHEMICAL AND PHYSICAL PHOTO-SENSITIVE SYSTEMS

Before the invention of electrophotography by Carlson, hardcopies were produced chemically with photo-sensitive materials. All such materials, except AgX's, suffering from dark reaction before use, resulted in low speeds, requiring large amounts of recording exposure. As the AgX system is inherently provided with the unique dark reaction cancelling mechanism, non-silver imaging systems had a necessity of relying on reversible or physical photo-response in order to reduce imaging exposure drastically.

Carlson process is honored not only with the invention of toner development, a new amplifier of photon action, but as the first reversible photo-sensitive system for hardcopy output.

These facts indicate

(1) Photo-sensitive imaging systems should be classified from the viewpoint of reversibility of their photo-responses.

(2) The speed of an irreversible system is governed by thermal noise except the AgX system which is free from thermal noise.

(3) The speed of reversible systems which are liberated from thermal noise are governed by internal noise, as pointed out by Shaw for electrophotography[1].

Among the internal noise, the significance of geometrical one will be stressed below

THERMAL VS GEOMETRICAL NOISE

My career started with an application of Carlson electrophotography to marking for ship building in 1957 surrounded by a host of photographic chemists.

After the success of the marking application, Fuji Photo commanded me to develop a xerographic continuous-tone printer. We started with liquid toning of ZnO paper for monochrome, then migration imaging and photo-electrophoresis for color, cooperating with Xerox without success. One reason for the failure evidently lies in that only analog technologies were available in sixties and seventies.

Through these failures, I found that a general drawback of electrophotography is its vulnerability to geometrical noise.

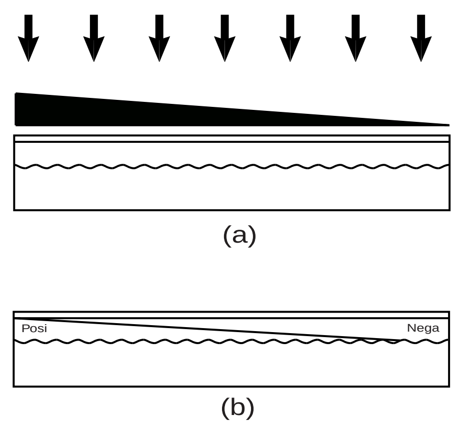

Fig.1; Geometrical noise in photographic film images. A wedge exposure to a film with coating non-uniformity (a) results in a posi image with geometrical noise which becomes relatively larger toward highlight (b).

The concept of this type of noise is clearly understood with silver halide film images (Fig.1)[3]. In the case of negative film, image density is macroscopically decided by the amount of exposure, the resulting noise being those from photon fluctuation and from microscopic grain distribution. In reversal film, in which the image sense is reversed by chemically removing the exposed grains to form an image with the unexposed grains. The image reversing mechanism introduces into the final image a new type of noise reflecting coating non-uniformity at low density areas, particularly at highlights.

In the practical reversal film production, such highlight noises are effectively suppressed by the use of a highly uniform base film and by adopting prudent coating and drying conditions compared to negative film production.

Carlson electrophotography, using an initially uniform surface potential of photo-sensor with corona charging, has an inherent difficulty in depicting the potential drop by image exposure regardless of image sense (Fig.2). Not only in latent image formation, but the subsequent steps (develop and transfer) tend to add geometrical noise to the final image because each step is often helped by electric field.

From Fig.2, it is evident that the noise of an electrophotographic latent image will remarkably decrease if the potential drop could be depicted by some means as in the case of vidicon.

How the two types of noise influence on the performances of various imaging systems are seen in Fig.3 where DQE is decomposed into two factors, i.e. primary quantum efficiency and internal noise[4]. It is evident that chemical or irreversible systems suffer from low primary efficiencies, unwilling measures for dark reaction suppression, while reversible ones suffer from internal noise.

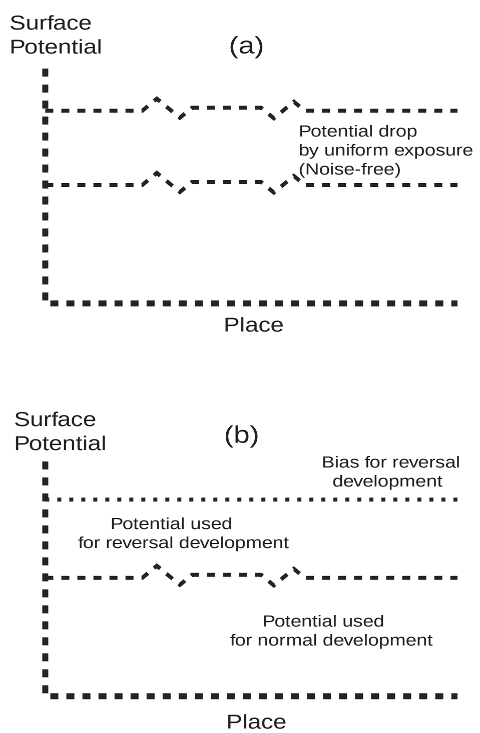

Fig.2;Surface potential of a xerographic photo-sensor before and after a uniform exposure (a), and the potential used for normal or reversal development.

HISTORY OF NON-SILVER X-RAY RECORDING

It is instructive to review the history of non-silver X-ray recording to understand the significance of geometrical noise. It should be kept in mind that in this application electrophotography in general has a clear advantage of the ease of manufacturing large area detectors.

First, xeroradiography achieved a success particularly in mammography. Then, for wider applications, ionography was proposed by Xonics[5]. Jeromin proposed, instead of toner development, to read with a microprobe the potential difference before and after X-ray exposure to the xerographic photo-receptor[6].

These and other trials were not commercialized owing either to practical inconvenience or poor image quality.

The final winner was Fuji Computed Radiography FCR which is based on a tailor-made, photo-stimulable phosphor[7]. The key to the success is the system design carefully excluding geometrical noise; the imaging plate, functioning without electric field, stores the genuine amount of excitation by X-ray photon, which is optically depicted and transferred to a low-noise AgX film.

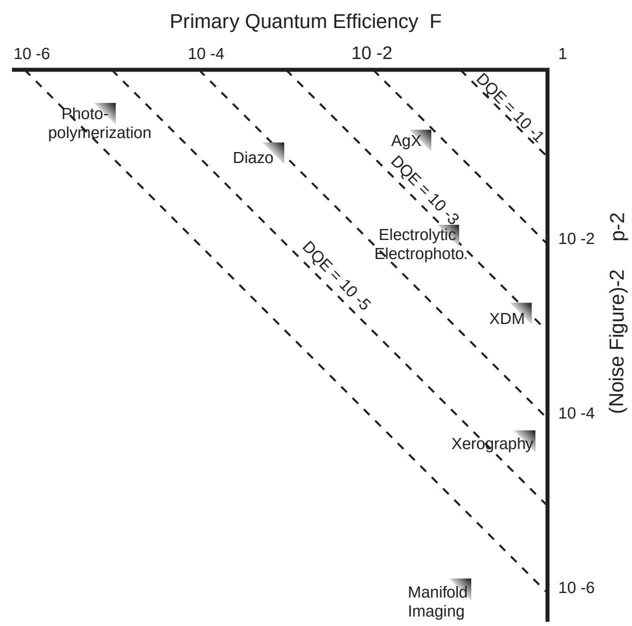

Fig.3; Characterization of various imaging systems in terms of primary quantum efficiency and internal noise.

SOME IMAGE QUALITY METRICS

In 1979, I moved to Ashigara Res. Lab., the R&D center for all AgX products.

My first job in Ashigara was to make AgX researchers recognize the superiority of AgX photography to other imaging systems in the chaos of silver shock.

I was forced to compare various hardcopy output systems with a common image quality metric that is readily understood by chemists, the majority of Ashigara Res. Lab.

Conventional metrics such as NEQ or information capacity, conceived by physicists were not familiar in Ashigara then.

By regarding a hardcopy output system as a tool for placing a pre-determined amount of image-forming colorants at a desired position, one can readily think of a value representing the minimum controllable amount of colorant (MCAC); i.e. the product of the density fluctuation on one pixel σ_s and the pixel area s.

$$MCAC = \sigma_s \; s$$

This value was originally proposed by Perrin for B/W film as "negative scale" [8] indicating the film area needed for extreme detail recording.

MCAC corresponds to the volume of the image-forming building block in the space defined by image plane and density axis.

Though the relation between density and the amount of colorant is not linear, In reflection print, this scale can be regarded as representing the fineness of image details.

Using this scale, I showed that MCAC of AgX systems is about 100 times as small as that of offset print at the extreme highlight [9]

Separately, from the noise analysis of a silver-catalyzed, dye-amplification system in which an exposed AgX grain is repeatedly used for dye formation in a H_2O_2-containing color developer, it was concluded that below 1mg/m^2 of Ag be needed for each color to realize a speed and image quality of xerography on analog basis. Since a typical cine-posi film uses 250 – 300 mg/m^2 of silver for each color recording, the factor of superiority is at least 100[10].

These and other comparisons contributed somewhat to restore researchers' confidence in the future of AgX photography. The world will remember Fuji Photo's achievements in the film industry in 80s.

IN THE DIGITAL ERA

Digital technologies have had a drastic effect on the color hardcopy output environment. Good quality prints other than photograph and offset print are now available.

Material Structure of Reflection Print

The new situation has revealed how the human eye is sensitive about the material structure of reflection prints[11]. This fact attracted my attention after my contract with Fuji Xerox in 1994, as they were nervous about the pile height of xerographic color images.

With the rapid quality improvement of digital printers, investigation of the customer's preference of the surface structure of reflection print is becoming more and more demanding because such preference may be one of the dominant factors for the future of photo-finishing market.

At present, the glossy surface of the conventional photographic print looks like a model, because, as Ide will discuss in this conference, a gloss distribution is perceived noisy by the observer.

Digital Chart

For many years, I chaired Group 1 of SEPJ's technical committee which has been in charge of image evaluation and have developed a series of test charts cooperating with Fuji Color Service Co.

In order to meet recent requests from the Society members, the committee now led by T.Inagaki is investigating technical possibilities of publishing a new type of digital chart. One of the possibilities will be discussed at the conference.

ACKNOWLEDGEMENTS

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