Polaroid Image Quality Methodology

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Abstract

Polaroid has developed a unified image quality methodology that has been used for over fifteen years to evaluate the image quality of both silver halide and digital imaging systems. The methodology includes: 1) Techniques to measure image quality; 2) Models for image quality based on objective metrics; 3) A system image quality calculator; 4) Device models for the hardware, media and image processing; 5) Data on the usage environment and customer habits. These methods are combined to measure or predict image quality distributions. Simulations of image quality have been useful in predicting the performance of new cameras and films and understanding the consequences of proposed changes in existing products. They help in risk assessment of forced manufacturing changes and in the design optimization of new systems. They have also been used in connection with digital systems to optimize image processing algorithms. The models have been verified by comparing predicted image quality distributions with those resulting from pictures taken by customers.

Introduction

People have common psychovisual expectations for the appearance of images. These expectations include factors such as the reproduction of lightness, the level of detail (sharpness), the level of variations in uniform areas (graininess), and the fidelity of colors, particularly memory colors. They result in a mutual concept of image quality. As a consequence, reproducible results are obtained when image quality is measured using a variety of different techniques.[1]

This common perception of image quality allows the solution to a critical problem in imaging system design—the optimization of the various components to deliver a product that satisfies the customer's quality expectations. In 1987 Polaroid began an effort to measure the contributions of various design parameters to the quality of the entire photographic system. Quality optimization schemes have been presented before, but most focus on a subset of the customer's experience. A recently disclosed Kodak methodology[2] does focus on the entire system. The Polaroid methodology was developed independently based on the same corporate need. One aspect in which the Polaroid methodology differs from Kodak's is in Kodak's use of just noticeable differences (JNDs). We have found that good manufacturing engineers tended to fall into a trap, by assuming that a fraction of a JND was a safe quality decrement since no one would notice. In our mind, the road to hell is paved in fractions of JNDs. We have developed a method that is more heuristic, but no less effective.

The Polaroid Image Quality Methodology both simulates and measures the quality of the system. It includes the photographer, the environment, the camera, image processing, and the print media. This methodology has been used to optimize the design of cameras, silver halide films, image processing algorithms, and thermal print media. It has also been used to reduce the variability of critical manufacturing processes.

Most of the component parts of this methodology have been previously presented. Image quality is determined through the use of a category scale.[1] Exposure and color balance shifts have been characterized by a colorimetric delta E* metric.[3] Sharpness and graininess metrics, modeled after those of Granger[4] and Bartleson,[5] have also been presented.[6] These individual metrics are combined using a system quality calculator. This calculator has been discussed in the context of software to automatically optimize not only the color but also the sharpness and grain of images within the context of ICC profiles.[7] The accuracy of the calculator had to be higher in this stand-alone application than in the system modeling discussed here since there was no image scientist reviewing each image. The device models for cameras, films, image processing and printers are straightforward.

Distributions of Quality

A single number does not describe the quality of an imaging system since not every variable is at its optimum all the time. In fact many variables have distributions of values. For example, the subject distance affects both image sharpness and flash exposure. As a result these input distributions combine to generate a distribution of quality.

It is, however, important to describe the performance when every variable is on aim. This defines the maximum or peak quality. The inherent sharpness and grain of the capture process often limit the peak quality. As important variables deviate from their ideal value, the quality distribution is asymmetrically broadened towards lower quality. For example, in a fixed-focus camera as the subject moves away from the point of best focus the image becomes less sharp. The photographic environment, the photographer, the camera, the printer and the reproduction media all contribute significant variation. If critical variables are not controlled, the quality distribution will be broad and the customer unhappy.

In the early phases of a project, the peak quality is tracked and optimized to determine the capability of the concept. In some cases, the modeling can optimize concepts prior to any physical realization. Later in the design process, the full distribution of quality is studied to determine appropriate design and manufacturing specifications. The mean quality is an important variable in this analysis because it predicts the customer's perception of overall quality better than the median, even though the median is a numerically more robust measure for these non-normal distributions.

Model

This methodology has been implemented using various models from simple spreadsheets to full analyses where there may be as many as 100 input distributions. For the full model, the input distributions are sampled using a Monte Carlo technique. Commercially available Monte Carlo simulation programs, designed principally for financial planning, have been used as well as custom programs.

Since this is a high level model, in many cases it uses the results of other studies. These can be closed-form models, such as the model for the MTF of the dye diffusion transfer that uses a hyperbolic secant. In other cases, approximations may be used to speed the calculation. For example, to calculate the exposure / color-balance error, the film sensitometry was converted to colorimetry using a quadratic approximation.

Input Distributions

Collecting reasonable distributions for these variables is a significant task. These distributions can be grouped into four categories: the photographic environment, camera/capture device, processing and film/media

Photography has an advantage over many consumer products, such as running shoes, in that the image records many features of the usage environment. The images themselves yield information on subject matter, subject distance, primary and secondary illuminants, processing temperature, camera orientation, *et cetera*. Polaroid has analyzed over 60,000 images from customer use tests to determine these distributions. The two dimensional photographic space[8] of subject distance and scene brightness is an example. Today the headers in the files from digital cameras capture some of this information.

The mean and standard deviation of a normal distribution can characterize some input variables, particularly those from manufacturing processes. Such a simple functional form, however, does not describe many of the environmental distributions. In fact, some are bimodal. The color temperature of the ambient illuminant at low light levels has a gap at 5000 Kelvin: *i.e.*, the common light sources are either tungsten or deep shade not sunlight. A table describing the cumulative distribution function is used to characterize these distributions.

Some of the camera and film distributions were simply the variability reported by manufacturing. Some were determined by laboratory experimentation. As an example of the latter, camera motion can be represented by a log normal distribution of the angular velocity of the handheld camera. Some users hold the camera very still, most hold it reasonably still and a few not still at all.

As a second example, registration errors in a multiple print head thermal printer combine to reduce the sharpness of the image. These distributions have been analyzed by measuring a machine readable registration target.[9]

Since image processing is usually deterministic, it generally was represented in the device models. Some algorithms, such analysis of the scene exposure,[10] do have distributions of residual errors.

Results

Polaroid's instant camera and film systems have been modeled extensively. One factor limiting peak quality is the MTF of the film. The image dyes diffuse across the100 μm gap from the negative to the image-receiving layer. Straightforward dimensional analysis results in a limiting resolution of ten line pairs per millimeter. Extensive research and development have made improvements in this sharpness, but it still limits the peak quality. As a result, ten years ago, the emphasis was changed to narrowing the image quality distribution. The model identified large contributors to errors from camera and film design and manufacturing. Manufacturing was willing to undertake the variability reduction effort only when they saw the impact on the customer as modeled using this methodology. The critical variables were then addressed resulting in a narrowed distribution and customer complaints fell.

More recently, we have used this methodology in the development of the "Opal" thermal printer. There are many causes of a blurry print from digital printers, including the size of the digital input file, the sharpness of the input image, the sharpening kernel, and the point spread of an individual pixel. In multiple print head thermal printers, the registration between the cyan and magenta color planes is important. The sources of variability are both static (such as head alignment) and dynamic (such as the bag and stretch of the media). We are in the midst of characterizing the registration and its impact on perceived sharpness in the context of distributions of input images.

Conclusions

This methodology has been useful in all phases of the life cycle of a product—from the conceptual phase to manufacturing improvements. It has prevented subsystem optimization from reaching too low a quality in which case it impacts the final system quality or from reaching too high a quality in which case it increases cost unnecessarily.

That this methodology differs from that of Kodak indicates that the solution is not unique. A methodology can be constructed using various subjective measuring tools and various quality models. The methodology can narrow the focus of experimentation even when it is quite crude. When it is more refined, it can indicate an optimum with little experimentation. Since it is a model, many concepts can be evaluated without the burden of building test devices.

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Biography

Julian Bullitt has an A. B. from Princeton University and received a Ph. D. in Inorganic Chemistry from M. I. T. in 1971. He joined Polaroid Corporation in 1974 where he has held various technical positions. Most recently he was a Research Fellow and Director of the Image Science Laboratory.

Bror Hultgren received his B.S. degree in Aeronautical Eng. from M.I.T. in 1962 and a Ph.D. in Physics from Boston University in 1975. Since 1979 he has worked in the Research Division of Polaroid Corporation. Most recently he was a Distinguished Scientist specializing in Image Science.