Low Dose Rate Imaging

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Abstract

The quality of low dose rate imaging strongly depends on the number of quanta that take part in the detected image. If quantum multiplication is applied, then the detective quantum efficiency of the imaging chain is an important imaging quality characteristic. Also the blur caused by the chain of imaging components that take part in the imaging process affects the imaging quality. For linear operating imaging devices this translates in the optical transfer function of the participating components. The fact that these qualifiers play a decisive role is based on the assumption that human perception is in a special way optimized for perceiving low dose rate images.

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1 Preface

The author started his career in high-tech industry in the development of image intensifier devices. His job was to help optimizing the imaging quality of these image intensifier devices. This concerned both image intensifiers for night vision applications and x-ray image intensifiers that were aimed at medical applications. Both types of devices target low dose rate application conditions. These devices achieve image intensification in quite different ways. Both types can be considered to operate in a linear way. The qualification of the image intensifier is based on the fact that human image perception is optimized for low dose rate conditions.

At low dose rates the author never perceived waves in the intensified images. At the utmost he saw hail storms of impinging discrete particles and the corresponding detection patterns can simulate interference patterns. The conclusion is, that the waves that might be present in the observed image are probability waves. Individual photons are perceived as detected quanta. They are never perceived as waves.

2 Human perception

With respect to visual perception the human visual trajectory closely resembles the visual trajectory of all vertebrates. This was discovered by Hubel and Weisel. They got a Noble price for their work.

The sensitivity of the human eye covers a huge range. The visual trajectory implements several special measures that help extending that range. At high dose rates the pupil of the eye acts as a diaphragm that partly closes the lens and in this way it increases the sharpness of the picture on the retina. At such dose rates the cones perform the detection job. The cones are sensitive to colors and offer a quick response. In unaided conditions, the rods take over at low dose rates and they do not differentiate between colors. In contrast to the cones the rods apply a significant integration time. This integration diminishes the effects of quantum noise that becomes noticeable at low dose rates. The sequence of optimizations do not stop at the retina. In the trajectory from the retina to the fourth cortex of the brain several dedicated decision centers decode the received image by applying masks that trigger on special aspects of the image. For example a dedicated mask can decide whether the local part of the image is an edge, in which direction this edge is oriented and in which direction the edge moves. Other masks can discern circular spots. Via such masks the image is encoded before the information reaches the fourth cortex. Somewhere in the trajectory the information of the right eye crosses the information that is contained in the left eye. The difference is used to construct three dimensional vision. Quantum noise can easily disturb the delicate encoding process. That is why the decision centers do not pass their information when its signal to noise ratio is below a given level. That level is influenced by the physical and mental condition of the observer. At low dose rates, this signal to noise ratio barrier prevents a psychotic view. The higher levels of the brain thus do not receive a copy of the image that was detected at the retina. Instead that part of the brain receives a set of quite trustworthy encoded image data that will be deciphered in an associative way. It is expected that other parts of the brain for a part act in a similar noise blocking way.

The evolution of the vertebrates must have installed this delicate visual data processing subsystem in a period in which these vertebrates lived in rather dim circumstances, where visual perception of low dose rate images was of vital importance.

This indicates that the signal to noise ratio in the image that arrives at the eyes pupil has significant influence on the perceptibility of the low dose image. At high dose rates the signal to noise ratio hardly plays a role. In those conditions the role of the spatial blur is far more important.

It is fairly easy to measure the signal to noise ratio in the visual channel by applying a DC meter and an RMS meter. However, at very low dose rates, the damping of both meters might pose problems. What quickly becomes apparent is the relation of the signal to noise ratio and the number of the quanta that participate in the signal. The measured relation is typical for stochastic quantum generation processes that are classified as Poisson processes.

It is also easy to comprehend that when the signal is spread over a spatial region, the number of quantal that participate per surface unit is diminishing. Thus spatial blur has two influences. It lowers the local signal and at the other hand it increase the integration surface. Lowering the signal decreases the number of quanta. Enlarging the integration surface will increase the number of involved quanta. Thus, these two effects partly compensate each other. An optimum perceptibility condition exists that maximizes the signal to noise ratio in the visual trajectory.

The blur is caused by the Point Spread Function. This function represents a spatially varying binomial process that attenuates the efficiency of the original Poisson process. This creates a new Poisson process that features a spatially varying efficiency. Several components in the imaging chain may contribute to the Point Spread Function such that the effective Point Spread Function equals the convolution of the Point Spread Functions of the components. Mathematically it can be shown that for linear image processors the Optical Transfer Functions form an easier applicable characteristic than the Point Spread Functions, because the Fourier transform that converts the Point Spread Function into the Optical Transfer Function converts the convolutions into simple multiplications.

The Optical Transfer Function is influenced by several factors. Examples are the color distribution, the angular distribution and the phase homogeneity of the impinging radiation. Also veiling glare may hamper the imaging quality.

The fact that the signal to noise ratio appears to be a deciding factor in the perception process has led to a second way of characterizing the relevant influences. The Detective Quantum Efficiency (DQE) characterizes the efficiency of the usage of the available quanta. It compares the actual situation with the hypothetical situation in which all generated quanta would be used in the information channel. Again the measured signal noise ratio is compared to the ideal situation in which the stochastic generator is a Poisson process and no binomial processes will attenuate that primary Poisson process. This means that blurring and temporal integration must play no role in the determination of the DQE and the measured device will be compared to quantum detectors that will capture all available quanta. It also means that intensification processes will not add extra relative variance to the signal. The application of micro channel plates will certainly add extra relative variation. This effect will be accounted as a deterioration of the detection efficiency and not as a change of the stochastic process from a Poisson process to an exponential process. Mathematically this is an odd procedure, but it is a valid approach when the measurements are used to objectively evaluate perceptibility.

2.1 Quantum physics

The fact that the objective qualification of perceptibility can be performed by the Optical Transfer Function in combination with the Detective Quantum Efficiency indicates that the generation of the quanta is governed by a Poisson process that is coupled to a binomial process, where the binomial process is implemented by a spatial Point Spread Function.