ANALYSIS OF NOISE IN TRACKING CAMERA

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ABSTRACT. The purpose of this document is to estimate the expected signal-to-noise ratio (SNR) in three different cameras: the ASI1600, ASI585MM Pro, and ASI432. By comparing their values, we will be able to argue for choosing a preferred camera.

1. Noise Model

The main sources of noise that we will consider are thermal, shot, and $1/f$ noise. We will estimate their mean square currents using their known spectral current noise densities. Derivations can be found in chapter 3 of [1].

Proposition 1.1. *The spectral current noise density of thermal noise is given by*

$$i_t^2 = \frac{4kT}{R},$$

where k is the Boltzmann constant, T is absolute temperature, and R the resistance through which the power is dissipated.

Proposition 1.2. *The spectral current noise density of shot noise is given by*

$$i_s^2 = 2qI,$$

where q is the charge of an electron and I is the average current in the system.

In our case of an image sensor, we take I to be the average photocurrent i_{ph}.

Proposition 1.3. *The spectral current noise density of $/1f$ noise is given by*

$$i_f^2 = \frac{A}{f^\alpha}, \quad \alpha \in [1/2, 2],$$

where A is some constant with units A^2/Hz depending on the properties of the system.

For simplicity, we take $\alpha = 1$.

2. Estimating Noise Levels

To get noise current from our noise current densities, we must integrate them over some frequency range. We determine the range by finding the system's bandwidth B and lower cutoff frequency f_l. For a CMOS image sensor, the bandwidth is limited by the integration time T, so we assume $B = 1/2T$ for each camera. For the lower cutoff frequency, it is practical to take $f_l = B/10$. Hence, we integrate

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over the range $[f_l, B]$. Doing this for thermal, shot, and $1/f$ noise respectively yields the mean square noise currents

$$I_t^2 = \int_{f_l}^{B} \frac{4kT}{R}\, df = \frac{4kT(B-f_l)}{R}$$

$$I_s^2 = \int_{f_l}^{B} 2qI\, df = 2qI(B-f_l)$$

$$I_f^2 = \int_{f_l}^{B} \frac{A}{f}\, df = A\log\left(\frac{B}{f_l}\right).$$

Adding these gives total mean square noise current

$$I_n = I_t^2 + I_s^2 + I_f^2.$$

3. Signal-to-noise ratio

Now that we have noise current, all that remains is to compute the signal current. If our laser has optical power P_o at the detector, then the photocurrent induced in the detector is $i_{ph} = R_\lambda P_o$, where R_λ is responsivity of the detector at a particular wavelength λ. We are not given the responsivity, so it must be estimated from the quantum efficiency (QE) as

$$R_\lambda = \frac{q\lambda\eta(\lambda)}{hc},$$

where q is the charge of an electron, λ is wavelength, η is QE, h is Planck's constant, and c is the speed of light. Hence, the SNR of each camera is given by

$$\text{SNR} = \frac{i_{ph}^2}{I_n} = \frac{(q\lambda\eta P_o/(hc))^2}{(4kT/R + 2q^2\lambda\eta P_o/(hc))(9/20T) + A\log(10)}.$$

References

[1] Helmuth Spieler *Semiconductor Detector Systems* Claredon Press, Oxford 2005