PHY 431 Homework Set #6

Due November 03 at the start of class

1) ***Still Camera (30%)***
   A. [Hecht 5.80] If a photograph of a moving merry-go around is perfectly exposed, but blurred, at 1/30 s and f/11, what must the diaphragm setting be if the shutter speed is raised to 1/120 s in order to "stop" the motion?
   B. If the camera lens is a diffraction-limited system, what is the angular resolution with the new setting (use λ=550 nm)?

2) ***Visual Acuity (35%)***
   A. The separation between cone cells in the fovea corresponds to about 1 min (0.3 mrad).
      a. At close viewing distance of 25 cm, what is the resolution?
      b. What is the diffraction-limited object size (at 25 cm) imposed by the numerical aperture of the eye (if the eye is a diffraction-limited optic)? Use 4mm for the iris diameter and 550 nm for the wavelength.
      c. What magnification is necessary for a telescope to enable a person with "normal" visual acuity to read letters 1 mm high, at a distance 400 ft? Note: the "normal" visual acuity is considered to be 1.0.
   B. Looking through a small hole is a well-known method to improve sight. If your eyes are near-sighted and can focus an object 20 cm away without using glasses, estimate the required diameter of the hole through which you would have good sight for object far away. (Assume the eye is 20 mm long.)

3) ***Accommodation/Myopia/Hyperopia (35%)***
   [Hecht 5.84] A patient is determined to have a near point at 50cm. If the eye is approximately 2.0 cm long,
   A. How much power does the refracting system have when focused on an object at infinity? When focused at 50cm?
   B. How much accommodation is required to see an object at a distance of 50 cm?
   C. What power must the eye have to see clearly an object at the standard near-point distance of 25 cm?
   D. How much power should be added to the patient's vision system by a correcting lens?

4) ***CCD Camera (*0.5 bonus point)***
   Working in a biology group as an undergraduate research assistant, you are assigned to work with Widget, on a project on fluorescent protein imaging in living cells. Your group just acquired a CoolSNAP High Resolution CCD camera (see attached spec sheet) from Roper Scientific, a well-known scientific CCD camera vendor in US. Unfortunately, Widget never took Physics 431; therefore, he comes to you for help to solve the following problems.
   A. Based on the well depth from the data sheet, what is the saturation intensity (W/cm^{-2}) of light of λ=600nm under 1.0 second integration (exposure) time? ***Well depth:*** The potential well in a CCD pixel will continue to collect all available electronic charges until it is filled with electrons. When this potential well is completely filled with charges, this is the saturation point of the detector and this is the maximum capacity of the potential well or the well depth.

B. The ***signal-to-noise ratio (SNR)*** for a CCD camera can be calculated as follows:

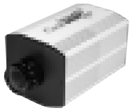
$$SNR = \frac{P \times Q_E \times t}{\sqrt{(P+B) \times Q_E \times t + D \times t + N_r^{\,2}}}$$

P=	Photo flux incident on the CCD (photons/pixel/second)
B=	Background photon flux incident on the CCD (photons/pixel/second) – background light can arise from may sources and is usually scattered light that is not of interest ot the observed – when the signal is the only source of light, B equals 0
Q_E=	Quantum efficiency of the CCD
t=	Integration/Exposure time (seconds)
D	Dark current (electrons/pixel/second) – dark noise equals the square root of Dt
N_r	Read noise (electrons rms/pixel)

The fluorescence wavelength λ=600nm, for P=50 photons/second and B=0,

1. Plot in log-log scale SNR vs. exposure time for t=0.1 to 100 seconds when the camera is operating at 10MHz digitization rate.
2. Depending on exposure time, noise is limited by read-nose or photon-noise. Label read-noise-limit and photon-noise-limit regions on the plot.

C. The proteins emit 1100 photons/second, what is the maximum number of frames you can capture per second to maintain SNR at least 10. And what is the data transfer rate when the camera is operating at this maximum frames/second rate?



DATA SHEET

COOLSNAP HQ SYSTEM

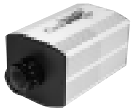
CoolSNAP HQ Monochrome

Photometrics

1392 x 1040 imaging array
6.45 x 6.45-µm pixels

The Photometrics CoolSNAP$_{HQ}$ Monochrome camera is a fast, high-resolution digital camera system designed for low-light scientific and industrial applications. This cooled CCD camera system provides 12-bit digitization at both 10 MHz and 20 MHz. The fine pitch of the pixels, 6.45 x 6.45 microns, is ideally matched to the resolution of optical microscopes. Megapixel resolution and small pixels allow imaging of very fine detail, yet the pixels can be easily binned to improve sensitivity. New interline CCD technology provides high quantum efficiency, most notably in the near-infrared (NIR) portion of the spectrum.

FEATURES	BENEFITS
10-MHz and 20-MHz digitization	Dual-mode readout for high-speed and high-sensitivity image capture
1392 x 1040 imaging array 6.45 x 6.45-µm pixels	Resolves fine detail Ideally matched to optical microscope
Interline, progressive-scan CCD	Electronic shuttering eliminates camera vibration and facilitates fast triggering
Flexible binning and readout	Increases light sensitivity while increasing the frame rate
12-bit digitization	Quantifies both bright and dim signals in the same image
Thermoelectric cooling	Long integration times for higher sensitivity
Enhanced quantum efficiency	Provides higher sensitivity, especially in the NIR, than typical interline cameras
C-mount	Easily attaches to microscopes, standard lenses, or optical equipment
PCI interface	Works with PC, Macintosh, or Linux®
Video output	Compatible with standard video equipment



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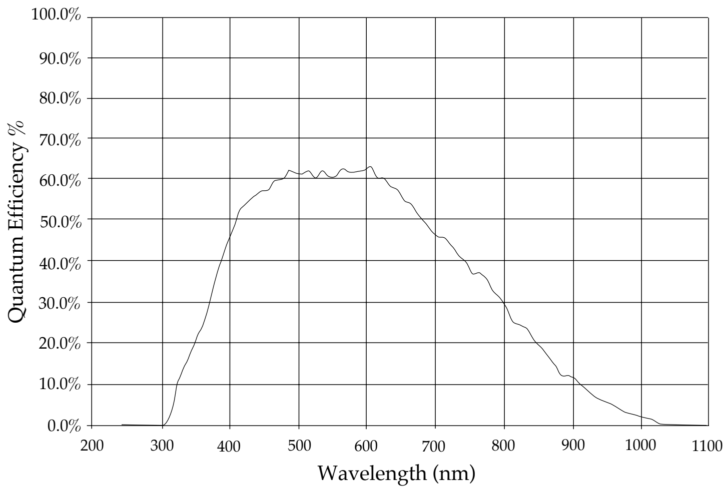

Region

Binning	1392 x 1040	512 x 512	256 x 256
1 x 1	10	19	30
2 x 2	18	30	44
3 x 3	24	38	51
4 x 4	29	43	56

(Frames per second)

Frame rates are measured at 20 MHz with 0-second exposure times.

SPECIFICATIONS

CCD image sensor	Sony ICX285; progressive-scan CCD
CCD format	1392 x 1040 imaging pixels; 6.45 x 6.45-µm pixels; 8.77 x 6.6-mm imaging area (optically centered)
Linear full well	15,000 e^- (single pixel); 30,000 e^- (2x2 binned pixel)
Read noise	6 e^- rms @ 10 MHz 8 e^- rms @ 20 MHz
Nonlinearity	<1%
Readout bits/speed	12 bits @ 20 MHz or 10 MHz; software selectable
Frame readout	100 ms/frame
CCD temperature	-30˚C regulated
Video output	RS170/PAL selectable
Dark current	0.05 e^-/p/s (-30˚C)
Operating environment	0 to 30˚C ambient, 0 to 80% relative humidity noncondensing

Note: Specifications are typical and subject to change.

ROPER SCIENTIFIC™
PHOTOMETRICS

3440 East Britannia Drive, Tucson, AZ 85706 tel: 520.889.9933 fax: 520.573.1944 email: info@roperscientific.com web: www.roperscientific.com