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2008 Imaging Science Ph.D. Comprehensive Examination
June 13, 2008
1:00PM to 4:00PM

IMPORTANT INSTRUCTIONS

You must complete six (6) of the eight (8) questions on this portion of the exam. The answer to each question should begin on a new piece of paper. While you are free to use as much paper as you would wish to answer each question, please only write on one side of each sheet of paper that you use. Be sure to write the identification letter provided to you this morning, the question number, and the page number for each answer in the upper right-hand corner of each sheet of paper that you use.

ONLY HAND IN THE ANSWERS TO THE SIX (6) QUESTIONS THAT YOU WOULD LIKE EVALUATED

Identification Letter: _____

THIS EXAM QUESTION SHEET MUST BE HANDED BACK TO THE PROCTOR UPON COMPLETION OF THE EXAM PERIOD

1. A commercial "4K" digital cinema projector projects a 4096x2160 image with a 4.2kW xenon bulb. It is based on a 3-chip liquid crystal on silicon (LCoS) projection engine that superimposes separate 4096x2160 R, G, and B images. It is rated at "18,000 ANSI lumens", but is advertised to automatically adjust the screen luminance so that it doesnt exceed 14 foot-lamberts.

    a. Given these parameters, make a recommendation for the minimum viewing distance for 10m-wide screen to avoid visible pixilation.

    b. Why should a digital cinema projection system automatically decrease screen luminance?

    c. "4K" projectors are coming for the home-theatre market. In order to keep costs down, one-chip designs incorporating RGB color-filter arrays (CFAs) over a single 4096x2160 LCoS image plane will be available. Discuss the tradeoffs in 1-chip CFA and 3-chip projector systems, and make a recommendation for the home market (i.e., would a 1-chip design be sufficient?) based on the characteristics of the human visual system. Assume a 65 screen (diagonal) and a minimum viewing distance of 2m.

2. You are developing a device for measuring the reflectivity of bats, as shown in Figure **??**. You make the following assumptions: The underside of the bat is a Lambertian reflector with area 0.01 m^2 and the bat's body is always *parallel* to the ground. You have a light source with a radiant intensity of 10^7 $[W\ sr^{-1}]$. You center it on a bat at an elevation of 8.6 degrees which yields a slant range of 2,000 meters. You observe a signal of 2.4 μA on a 0.001 m^2 detector lying on the ground 2,050 meters from the light source. What would the bat's reflectivity be if the sensor has a responsivity of 2×10^6 amps per watt?

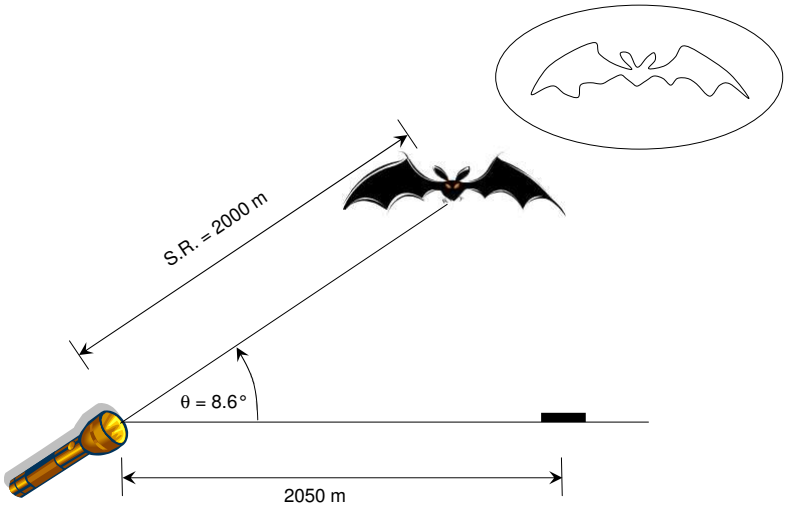

Figure 1: Geometry for measuring the reflectivity of bats.

3. In the year 1910 the physicists Rutherford, Geiger, and Bateman observed the number of α-particles emitted by a lm of polonium. Each observation interval was 7.5 seconds and the intervals did not overlap. The observation data is shown in the table. From these data, calculate the average rate in emissions per interval. Then compare the values in the table to the values you would expect for a Poisson distribution and comment on the validity of the Poisson model for this experiment.[1]

Number of Events in One Interval	Number of Such Occurrences	Calculated Value
0	57	
1	203	
2	383	
3	525	
4	532	
5	408	
6	273	
7	139	
8	45	
9	27	
10	10	
11	4	
12	0	
13	1	
14	1	
15 or more	0	

[1] http://www.umass.edu/wsp/statistics/lessons/poisson/problems.html

4. Consider two ideal (aberration-free) optical imaging systems "A" and "B" with the same focal length $f = 400mm$ to be used with *coherent light* with $\lambda_0 = 450nm$. The images created by the two systems are recorded using identical CCD detectors that have square pixels with linear dimensions $b = 9\mu m$. The pupil functions are:

$$p_A(r) = \delta(r - 50mm)$$

$$p_B(r) = CYL\left(\frac{r}{100mm}\right)$$

   a. Which system would you expect to exhibit better *spatial resolution*? Explain your answer, including any issues that would need to be evaluated before a definite answer may be determined.

   b. Which system would you expect to exhibit better *sensitivity* - in other words, which would require less incident amplitude to obtain an image of the same quality? Explain your answer.

   c. The CCDs that you have available to use as sensors in this system have linear dimensions EITHER of $b_1 = 9\mu m$ or $b_2 = 5\mu m$. The the "filled-aperture" with $p_B(r)$ is used for imaging, determine an appropriate value for the pixel dimension b for this system. Explain your answer.

5. Using integral calculus, derive an expression for the angular intensity $I(\theta)$ as a function of radiant flux Φ from a Lambertian surface. Hint: $\int \cos x \sin x \, \mathrm{d}x = \frac{1}{2} \sin^2 x$

6. Hecht, Shlaer, and Pirenne performed a classical experiment to determine the absolute sensitivity of the human visual system, ultimately determining that under ideal conditions photodetectors can respond to the energy in a single photon.

   Describe the variables and parameters that constitute those ideal conditions and discuss the reasons for each parameter choice.

7. You have been given three thin lenses with the following prescriptions:

$$L_1 : n = 1.5, R_1 = +400mm, R_2 = -400mm$$

$$L_2 : n = 1.7, R_1 = -300mm, R_2 = +300mm$$

$$L_3 : n = 1.6, R_1 = -400mm, R_2 = +400mm$$

a. Find the focal length of all three lenses.

b. Find the focal length of all three two-lens pairs if the lenses are placed in contact.

c. For an object at infinity, determine the separation of the lenses required to make telescopes for all six combinations (objective L_1, ocular L_2; objective L_2, ocular L_1; etc.) AND determine the transverse and angular magnifications in each case.

8. A source produces photons at a rate of 8 photons in 10 seconds. Let $N(t)$ be the number of photons in the interval $(0, t)$ seconds. What is the probability that $15 \leq N(20) \leq 17$ given that $7 \leq N(10) \leq 9$?