EE119 Homework 6: Cameras and Telescopes

Professor: Jeff Bokor GSI: Julia Zaks

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1. (a) If a photograph of a race car is perfectly exposed, but blurred, at a shutter speed of 1/30s and and aperture stop setting of f/11, what must the aperture stop setting be if the shutter speed is raised to 1/120s in order to stop the motion? Give your answer as an F# number. (See p. 44 of the notes)

   (b) If the camera lens is a diffraction limited system, what is the resolution limited angle at the new setting (use 500nm for the wavelength)?

2. You buy a new digital camera and want to test your skills by photographing two ninjas sparring. The cameras shutter speeds are: 1-1, 2-1, 4-1, 8-1, 16-1, 32-1, 64-1, 125-1, 250-1, 500-1, and 1000-1, and the aperture stops (F-stops) are 2, 2.8, 4, 5.6, 8, 11, and 16.

   (a) You took a picture of a ninja's fist flying through the air (with 1/16 s and f/16) and found that the image is blurred. Now you decide to use a faster shutter speed 1/32s to obtain a sharper image. What should be the corresponding aperture stop (F-stop?).

   (b) In your original picture (with 1/16 s and f/16), the ninja's fist was about to smash a board in half. You were positioned behind the fist, and you were able to have both the board and the fist just barely in focus. Will both objects still be in focus with the new settings you found in part a?

   (c) If the setting found in part (a) is barely good enough to take a sharp picture of the ninja's fist (30mph), can you take sharp pictures of the fist of the world-class ninja who can move three times faster? Assume that the required shutter speed is inversely proportional to the speed of the moving object. That is, the new shutter speed will have to be three times faster. Find the settings required to take sharp pictures of the world-class ninja's fist.

   (d) If the settings on your camera remain the same, will using larger film change your picture? If so, how?

3. Captain James Cook is sailing through the south pacific on a mission from the Royal society to observe the passage of Venus across the sun. He has a telescope with him, but he doesn't know how good it is, so he brings you along to help him figure it out. The eyepiece of the telescope is 2 cm in diameter and has a focal length of 4 cm. The clear aperture of the exit pupil is 0.35 cm. The telescope has an angular magnification of 45. Assume normal visual acuity, which means that the spacing between the detectors in the eye of the viewer is 0.3 milliradians.

   (a) What is the focal length of the objective lens?

   (b) What is the diameter of the objective lens?

(c) What is the object field angle? The object field angle is the maximum angle that defines the field of view of the telescope due to the diameter of the lenses (and not to diffraction)

(d) What is the image field angle?

(e) What is the limit of the telescope's resolution due to diffraction?

(f) Captain Cook sees a ship in the distance, and he wants you to tell him if the ship is a pirate ship or a friendly merchant ship. The black flag of the ship has white letters, so the only way to distinguish it from a pirate ship with a skull and crossbones is to read the text on the flag. You can read the text on the flag if you can separate features that are 10 cm apart. Using this telescope you've just analyzed, how close do you have to be to the ship before you can tell Captain cook if you're dealing with merchants or pirates?

4. Captain Cook decides that he wants you to modify his telescope to make it more useful for observing the night sky. He wants you to increase the clear aperture of the exit pupil to 8 mm to make it practical to view at night. Design an astronomical telescope which can resolve an object on the moon which is 1/50 the size of the moon (the moon is 3476 km in diameter and orbits at roughly 384,300 km from the earth). Captain Cook doesn't like wasting money, so he doesn't want you to make any of the lenses larger or more powerful than they need to be. Assume normal visual acuity. Your solution should include

   - the overall magnification of the telescope
   - a diagram and ray trace of the system;
   - focal lengths and diameters of the lenses;
   - sizes of the aperture stop, entrance pupil, and exit pupil;
   - The limits on the resolution of the telescope due to diffraction and your eye's resolution

   Since this is a design problem, there is no one right answer, so it is very important for you to clearly explain each step and make it easy for whoever is reading your problem to understand your reasoning.