Midterm Exam

CS/ECE 181B – Intro to Computer Vision

May 6, 2003

9:30-10:45am

Please space yourselves so that students are evenly distributed throughout the room. If possible, there should be no one directly next to you.

This is a closed-book, closed-notes test. There are a few pages of equations, etc. included for your reference.

Be sure to read each question carefully and provide all the information requested.

Write your answers in the spaces provided and, if necessary, on the back of the page. If you use the back, draw an arrow or write “SEE BACK” to make sure the graders don’t miss it. If you need more space, attach extra sheets of paper (available at the front).

Exams must be turned in by 10:45am sharp.

Good luck!
Midterm Questions

1. [5 points] The aspect ratio of a particular image is 4:3 (width:height), and its pixels also have a 4:3 aspect ratio. If the image has a width of 640 pixels, what is its height in pixels?

   Also 640 pixels in height.
   (Notice that the pixels are not square ones. They are rectangles with the aspect ratio of 4:3, too.)

2. [5 points] Describe one significant advantage of CMOS imagers over CCD imagers.

   The most significant advantage of CMOS imagers over CCD imagers is that CMOS is LESS EXPENSIVE.
   ("Lower power" is also an acceptable answer.)

3. [5 points] In a perspective projection with a focal distance of $f=5$, the scene point (-15, 10, -40) projects to what point on the virtual image plane?

   On the VIRTUAL image plane, the coordinates can be calculated by
   \[
   \begin{align*}
   x' &= -f \frac{x}{z} = -5 \times \frac{-15}{-40} = -1.875 \\
   y' &= f \frac{y}{z} = -5 \times \frac{10}{-40} = 1.25 \\
   z' &= -f \frac{z}{z} = -5 
   \end{align*}
   \]

4. [5 points] Of the following projection models: **perspective**, **orthographic**, **parallel**, **weak-perspective**, and **paraperspective**, for which ones do all projected points pass through the origin of the camera coordinate system?

   Perspective, weak-perspective and paraperspective.
5. [5 points] For a given lens, a scene point at \( z = -10 \) focuses on the image plane at \( z' = 2 \). For the same lens, where will a scene point at \( z = -20 \) focus? 

Use the lens formula \( \frac{1}{z'} - \frac{1}{z} = \frac{1}{f} \).

When \( z = -10 \) and \( z' = 2 \), we have \( \frac{1}{2} + \frac{1}{10} = \frac{1}{f} \).

When \( z = -20 \), we have \( \frac{1}{z'} + \frac{1}{20} = \frac{1}{f} \).

So \( \frac{1}{z'} + \frac{1}{20} = \frac{1}{2} + \frac{1}{10} \).

\( z' = \frac{20}{11} = 1.818 \)

6. [5 points] Which is easier to correct for: radial distortion or chromatic aberration? Why?

Radial distortion is easier to correct for. It can be modeled and corrected for. But chromatic aberration cannot be corrected for. We can use the combination of lenses (e.g., a convex and a concave) to reduce it, but we cannot correct it.

7. [5 points] Give the 4x4 homogeneous transformation matrix that first translates a point by \([1 \ 2 \ 3]\) and then rotates it about the \( z \) axis by 45 degrees.

\[
T = T_{\text{Rotation}} \times T_{\text{Translation}} = \begin{bmatrix}
\cos 45^\circ & -\sin 45^\circ & 0 & 0 \\
\sin 45^\circ & \cos 45^\circ & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
1 & 0 & 0 & 1 \\
0 & 1 & 0 & 2 \\
0 & 0 & 1 & 3 \\
0 & 0 & 0 & 1
\end{bmatrix} = \begin{bmatrix}
\sqrt{2}/2 & -\sqrt{2}/2 & 0 & -\sqrt{2}/2 \\
\sqrt{2}/2 & \sqrt{2}/2 & 0 & 3\sqrt{2}/2 \\
0 & 0 & 1 & 3 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

8. [5 points] In some cases, six fiducial (reference) points are theoretically sufficient to do camera calibration. Why would we normally want to use more than six?

The main reason is for numerical stability (less sensitive to small errors).

Another good reason is that we need more independent points. It’s always better to use independent points to get the parameters we need to do the camera calibration.
9. [5 points] A red surface is being illuminated by a white light. The surface has a reflectance function that is Lambertian+Specular (some components of each). What color will the specular highlights be, and why?

Perfect answer: PINK (very bright pink). At the highlight point, all white lights are reflected and because of the Lambertian surface, a small amount of red light is also reflected. So the mixture of a big amount of white light and a small amount of red light is very bright pink.

“White” is also OK.

10. [5 points] For human vision, list at least two factors, besides wavelength, that determine the color we perceive a certain scene point to be. Do these affect the RGB color values that a camera produces from that scene point?

Any of the following is OK.
- Surrounding color, brightness
- Adaptation state, bleaching state
- High-level interpretation of scene

They don’t affect the RGB color values produced by a camera.

11. [5 points] How many entries will there be in the colormap for an indexed color image that is 640x480 pixels, 10 bits per pixel?

The problem is actually: how many different colors can be represented by 10 bits?
So the answer is $2^{10} = 1024$ entries.

12. [5 points] Two light sources, A and B, are metamers – they produce the exact same RGB pixel values. Now we mix them together to create two new light sources, X and Y, as such:

\[
X = \frac{1}{3} A + \frac{2}{3} B \\
Y = \frac{2}{3} A + \frac{1}{3} B
\]

Are X and Y metamers? Explain why or why not.

Yes, X and Y are metamers. Because they are linearly combined.
Another good explanation: A and B are metamers, so they should project to the same point on the receptor surface. Since X and Y are combined by those linear functions, X and Y are on the line formed by A and B. So X and Y have the same projection point on the receptor surface, too. So X and Y are metamers.
13. [5 points] A light source produces chromaticity coordinates (0.2, 0.2). A finite amount of a second light source is added to the first source to create white light. The tristimulus values of this second light are (100, 100, Z). What are the allowable values of Z?

The possible position of the second light is shown by the blue line segment in the CIE diagram. So the coordinates should satisfy

\[
x = \frac{100}{100 + 100 + Z} > 0.333 \quad \Rightarrow Z < 100.
\]

\[
y = \frac{100}{100 + 100 + Z} > 0.333
\]

And we know that Z is bigger or equal to zero.
So \(0 \leq Z < 100\)

14. [5 points] The chromaticity coordinates calculated at a particular point on the image plane are (0.5, 0.3). If a filter is placed on the camera that blocks out 50% of the incoming light equally at all wavelengths (this is called a “neutral density filter”), what are the chromaticity coordinates at the same point in the resulting image?

Still (0.5, 0.3)
15. [6 points] On the CIE diagram below:
   a. Draw and label a point \( q \) that has the same hue as point \( p \) but is more highly saturated.
   b. Draw and label a point \( r \) that is an equal mixture of monochromatic sources of 380 nm and 600 nm.

\( r \) is the midpoint of the blue line segment.
\( q \) can be anywhere on the purple line segment.
16. [5 points] A certain point on a scene object reflects an amount of radiance towards the camera, where the irradiance causes a pixel value of 100. The point is along the camera’s optical axis, so it is imaged in the center of the image (left figure). If the camera is rotated 15 degrees (right figure), and all else remains the same, what should the pixel value of that same point be?

For thin lenses radiometry, we know that 
\[ E = \left[ \frac{\pi}{4} \left( \frac{d}{z} \right)^2 \cos^4 \alpha \right] L. \]
When you rotate the camera, only \( \alpha \) is changed from 0 to 15 degrees. So we have
\[ \frac{E_2}{E_1} = \frac{\cos^4 15^\circ}{\cos^4 0^\circ} \]

So \( E_2 = E_1 \times \cos^4 15^\circ = 100 \times \cos^4 15^\circ = 87 \)

17. [5 points] What 3D point \( p = (x, y, z) \) is produced by adding the following 3D points, represented in homogeneous coordinates:

\[ p_1 = \begin{bmatrix} 2 \\ 3 \\ 6 \\ 2 \end{bmatrix} \quad \quad p_2 = \begin{bmatrix} 4 \\ 3 \\ 0 \\ 4 \end{bmatrix} \]

\[ p_1 = \begin{bmatrix} 2 \\ 3 \\ 6 \\ 2 \end{bmatrix} = \begin{bmatrix} 1 \\ 1.5 \\ 3 \\ 1 \end{bmatrix} \quad \quad p_2 = \begin{bmatrix} 4 \\ 3 \\ 0 \\ 4 \end{bmatrix} = \begin{bmatrix} 1 \\ 0.75 \\ 0 \\ 1 \end{bmatrix} \]

The 3D points represented by \( p_1 \) and \( p_2 \) are \([1 \quad 1.5 \quad 3]^T\) and \([1 \quad 0.75 \quad 0]^T\). So \( p = p_1 + p_2 = [2 \quad 2.25 \quad 3]^T \).