CS-512 – Assignment 1 (4%)

Image formation

Due by: September 26, 2017

Answer the following questions. Make sure that your answers are concise. In questions requiring explanation, make sure your explanation is brief.

1. Geometric image formation:

    (a) Let f=10 be the focal length of a camera. Let p=(3,2,1) be a world point. Find the coordinate of the point p when projecting it onto the image. Assume that the projection is done in camera coordinates so there is no need for a transformation between coordinate systems.

    (b) Explain the difference between the pinhole camera model where the image plane is behind the center of projection and the pinhole camera model where the image plane is in front of the center of projection. Which model corresponds better to a physical pinhole camera model? How is the other model justified?

    (c) Explain what happens to the projection of an object when the focal length gets bigger and what happens to the projection when the distance to the object gets bigger.

    (d) Given the 2D point (1,1) find its coordinates in homogeneous coordinates (2DH). Find another 2DH point that corresponds to the same 2D point.

    (e) Give the 2DH point (1,1,2), find the 2D point corresponding to it.

    (f) Explain the meaning of the 2DH point (1,1,0).

    (g) Explain what makes it possible to write the non-linear projection equation as a linear equation in homogeneous coordinates.

    (h) Given the projection matrix $M = K[I|0]$ write the dimensions of M and the sub-matrices K,I,0.

    (i) Given a projection matrix M whose rows are [1,2,3,4],[5,6,7,8],[1,2,1,2], and a 3D point P=[1,2,3], find the coordinate of the 2D point p obtained by projecting P using M.

2. Modeling transformations:

    (a) Given the point (1,1) find its coordinates after translating it by (2,3). Perform the computation using a transformation matrix.

    (b) Given the point (1,1) find its coordinates after scaling it by (2,2). Perform the computation using a transformation matrix.

    (c) Given the point (1,1) find its coordinates after rotating it by 45 degrees.

    (d) Given the point (1,1) find its coordinates after rotating it by 45 degrees about the point (2,2).

    (e) Given that I want first to rotate an object using a matrix R and then translate it using a matrix T, what should be the combined matrix (expressed in terms of R and T) that needs to be applied to the object.

(f) Let M be a 2D transformation matrix in homogeneous coordinates whose rows are [3,0,0],[0,2,0],[0,0,1]. What is the effect of applying this matrix to transform a point p.

(g) Let M be a 2D transformation matrix in homogeneous coordinates whose rows are [1,0,1],[0,1,2],[0,0,1]. What is the effect of applying this matrix to transform a point p.

(h) Let M be a 2D transformation matrix in homogeneous coordinates whose rows are [3,0,0],[0,2,0],[0,0,1]. What is the transformation matrix will reverse the effects of this transformation?

(i) Let M=R(45)T(1,2) be a transformation matrix in homogeneous coordinates composed of rotation by 45 degrees and a translation by (1,2). Express the inverse of this transformation in terms a rotation and translation matrix.

(j) Find a vector which is perpendicular to the vector (1,3).

(k) find the projection of the vector (1,3) onto the direction defined by the vector (2,5).

3. General camera model:

   (a) Explain the need for a general projection matrix that uses different coordinate systems for camera and image.

   (b) Given that the camera is rotated by R and translated by T with respect to the world, write the transformation matrix that will convert world to camera coordinates.

   (c) Given three unit vectors $\hat{x}, \hat{y}, \hat{z}$, write the rotation matrix describing the rotation of the camera with respect to the world.

   (d) Given the transformation matrix between world and camera coordinates $M = \begin{bmatrix} R^* & T^* \\ 0 & 1 \end{bmatrix}$ explain the meaning of R^* and T^*.

   (e) Given that there are k_u pixels per mm in the x direction, k_v pixels per mm in the y direction, and that the optical center of the camera is translated by $(u_0, v_0) = (512, 512)$ pixels, write the transformation matrix that will convert camera coordinates to image coordinates.

   (f) Let the projection matrix M of a general camera be given by $K^*[R^*|T^*]$. Explain which parts contain the intrinsic and extrinsic parameters of the camera.

   (g) Explain the reason for including a 2D skew parameter in the camera model.

   (h) Explain what happens to the camera model when taking into account radial lens distortion. What is the complication introduced by the radial lens distortion?

   (i) Explain the meaning of a weak-perspective camera and of an affine camera.

4. Color and photometric image formation:

   (a) Explain the difference between surface radiance and image irradiance.

   (b) Write the radiosity equations relating surface radiance and image irradiance.

   (c) Define the albedo of a surface.

   (d) Explain what is the reason for using the RGB color model to represent colors.

   (e) Given the RGB color cube, what are the colors along the line that connects (0,0,0) with (1,1,1).

   (f) Explain the way by which RGB colors are mapped to real-world colors.

   (g) Given the CIE RGB color model and its conversion to the XYZ model, explain what is the use for the luminance component Y.

   (h) Explain the advantage of the LAB color space.

5. Use Python to solve the questions of assignment 0 sections A, B, C.

Submission Instructions:

1. Create a folder AS1 in your bitbucket repository and create inside it the following sub-folders: `src`, `doc`, and `data`. Organize the submission materials inside the sub-folders as follows:

   (a) `doc`: Report prepared as a PDF file. The report should contain answers to questions, a summary of program design issues, description of specific problems you faced and the way in which you solved them, and sample input/output results (text/graphic). The report needs to be sufficiently detailed. It is very important that you evaluate the algorithms you implemented for correctness and for performance. Try using different parameters and observe (and report) the effect of the parameters.

   (b) `src`: All program files.

   (c) `data`: All data files (e.g. test images).

2. Note that we must be able to view your report and execute your program in order to grade it.

3. For programming questions use OpenCV and Python (support code will be provided).

4. On or before the due date upload your submission to your bitbucket repository. If you are late, upload the submission when you are ready and send an email to *cs512@cs.iit.edu* saying you made a submission. To compute "late days will" we will use the last update date of your repository.

5. Direct all questions/comments regarding the assignment to: *cs512@cs.iit.edu*

6. Do not submit a paper copy of your report. You will be contacted by email if some material is missing or if you will need to meet with the TA.