Computer Vision Fundamentals: Homework 2

Instructor: Sohaib Khan (Rm 407)
TA: Raqib Mian (CV Lab, opp Rm 407)

Assigned: Saturday 11th October 2008
Due: Monday 20th October 2008

All additional tasks for MS students can be attempted by BS students for extra credit.

BASIC PROBLEMS (40 points)

1. Prove that under the planarity assumption for the world, the image seen by two orthographic cameras is related by the affine transformation.

2. A camera is located such that its gimbal is at (0, 2, 2). The offset of the gimbal to the center of the image plane is (0.02, 0.01, 0.03). The camera has been rotated (with gimbal as center of rotation) about X-axis by 135° followed by rotation about Z-axis by 90°. The focal length of the camera is 0.03. Assume an ideal pinhole camera. Find the image coordinates of the point that has world coordinates (1, 1, 0.2).

3. If an object in the world undergoes rigid motion, will the area of the object remain the same in the image under orthographic projection? Explain your answer.

4. A camera is mounted in a vehicle. The initial position of the vehicle such that the camera is at the world origin, with positive X-axis going out of the left side of the vehicle, positive Y-axis pointed upwards and positive Z-axis in front of the vehicle, as shown. The Z-axis of the world is aligned with the North of the compass.

   When the vehicle turns, it can be assumed that it turns about its center of mass, which is ½ m above the ground. The gimble vector, from the point of rotation of the camera to the image center is negligible. The location of the camera is [0, 1, 0] (in meters) with respect to the center of mass of the vehicle. The camera is oriented such that it is vertically upright; it is looking at a point on the road directly in front of the vehicle and is tilted downwards at an angle of 30°.

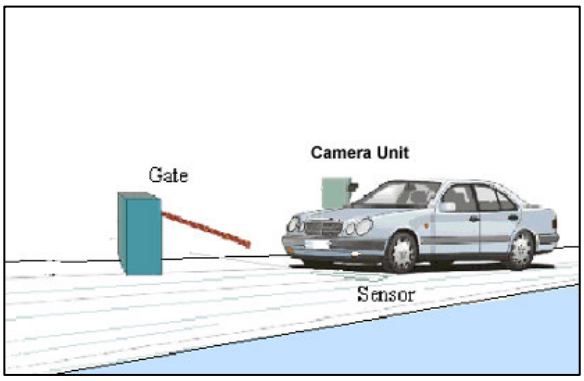
   The vehicle travels to a location that has coordinates 200m along X-axis and 100m along Z-axis along a level road. At that moment, the vehicle is headed NW.

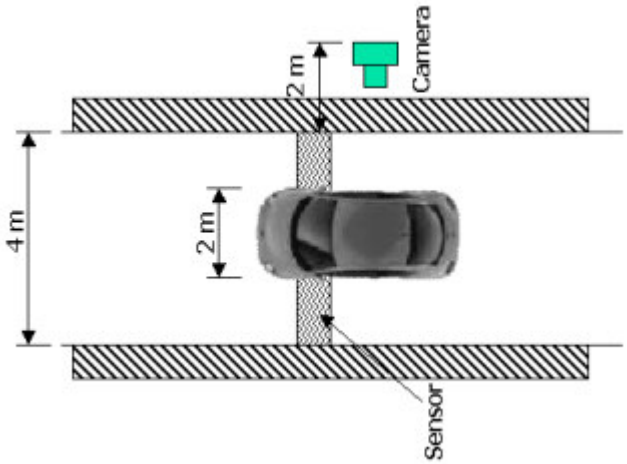
   If the focal length of the camera is 2cm, compute the camera model for this scenario. (You may write the expression in terms of product of matrices).

5. [*For MS Students*] Show that for a pinhole camera, three collinear points in the 3-D space are mapped to three collinear points on the image plane.

6. [*For MS Students*] Show that every rotation matrix (regardless of the dimensionality of the space) is necessarily an orthogonal matrix. Moreover, show that every rotation matrix must also have a determinant of 1.

DESIGN PROBLEMS (60 points)





7. A parking garage owner wishes to protect against false damage claims by customers, and has decided to invest in a camera system to take the pictures of every car as it enters and exits the garage. The pictures will be archived for future evidence. If an owner later claims that the car was scratched or damaged while parked, the owner should be able to verify or refute that claim by looking at the archived pictures. He has hired you for help.

   Figure (a) shows the arrangement of one camera that will be used to cover the entire right side of the vehicle. Figure (b) shows the same arrangement from the top. (The figures are NOT drawn to scale). When the front wheels of the vehicle pass over the sensor, the camera takes the image. At that moment, the optical axis of the camera is looking approximately at the center of the vehicle.

   The owner has provided the following estimates: The vehicle can be assumed to be of 2m width traveling anywhere in a lane which is 4m wide. The camera is mounted such that its center of lens is 2m from the edge of the lane. The typical length of a vehicle that enters the garage is 4m.

   The requirement of the owner is that for every vehicle that passes over the sensor, the image should be of such a high quality that a scratch of 2mm thickness should be clearly visible in the image. The image should also contain the whole vehicle in all cases. You may assume that for a feature to be clearly visible, it must map to at least one pixel in the image.

   a. What is the minimum horizontal resolution of the camera that is needed? That is, what is the minimum number of pixels that the camera must have in the horizontal direction to meet the requirement specifications?

   b. The camera that is available has adjustable focal length. It has enough number of pixels that you need, as computed in part (a), fitted in a CCD array of width 40mm. What focal length can you set to meet the requirement specifications?

8. For security at an airport, you are asked as a consultant to design a system which can be installed at the entrance of the airport and will take the complete image of the under-side of a vehicle. The cameras which have a horizontal and vertical field of view of 75º will be installed on the road looking upwards. They will take the video of an incoming car at 30 frames per second. The video will later be mosaiced together to form a single image of the under-side of a vehicle.

   The speed of the vehicle passing over the camera can be up to 10 km/hr. The height of the vehicle above the camera depends on the type of the vehicle, and can vary from 5 cm to 20 cm. Each image that the camera captures is 1000x1000 pixels.

   a. For mosaicing to work well, it is a requirement that there be at least a 50% overlap of content between two consecutive frames. Given the above values, determine whether this constraint of 50% overlap is always met in the above scenario or not. You may assume that the shutter speed is high enough to not generate any motion blur.

b. Which parameters may you change in the design of the system to increase the amount of overlap between successive frames? Discuss the effect of each parameter.

c. Provide a few different design solutions which will meet the 50% overlap specification, and show the validity of those solutions.

9. In cricket coverage on TV, advertisements are frequently shown painted on the cricket ground. The ads are painted such that from a particular camera viewpoint, they appear as 'vertical' billboards, even though they are really horizontal on the ground plane. An example of such an ad is shown in the figure on the right. We assume that the camera is fixed and cannot move, nor can its focal length be changed.

a. What must be the shape of the ad when viewed from vertically above?

b. What type of transformation exists between the standard ad and the transformed ad?

c. Given that the camera parameters are known, clearly outline a process to determine the coordinates of the ad to be drawn on the ground.

ADDITIONAL PROBLEM FOR MS STUDENTS (20 points)

10. Camera Calibration: In this problem, you are required to calibrate a camera. You may use the cameras and frame-grabbers in the vision lab if needed. The goal is to calibrate a camera, and then do an experiment to verify the accuracy of the calibration parameters. You may not use any existing calibration toolbox; instead you have to write your own code. You have to submit a written document explaining your approach and results. You may be required to give a demo after the homework is due.