Computer Vision **CS 543 / ECE 549**

Homework 3
Due Mar 13, 2012

Answer the following questions and explain solutions. Numbers in parentheses give maximum credit value. You can discuss in small groups, but turn in individual solutions and indicate collaborators. Do not use code from the Internet or high-level functions from within Matlab (such as image pyramid or edge detection functions), unless specific permission is given.

Turn in assignments by Tuesday, Mar 13. *Electronic materials (e.g., pdf, code) should be submitted by 12:00pm (noon) by e-mailing Ruiqi Guo with the subject line: CV:HW3. Hard copies can be handed in at the start of class, 2pm.* **Put your name on any assignment, and if using electronic submission, put figures within a single document.** You can turn in a mix of hard copy and electronic (e.g., hard copy for writing down equations or drawings, electronic for images), but if you do so, indicate on your hardcopy which portions you sent in electronic format.

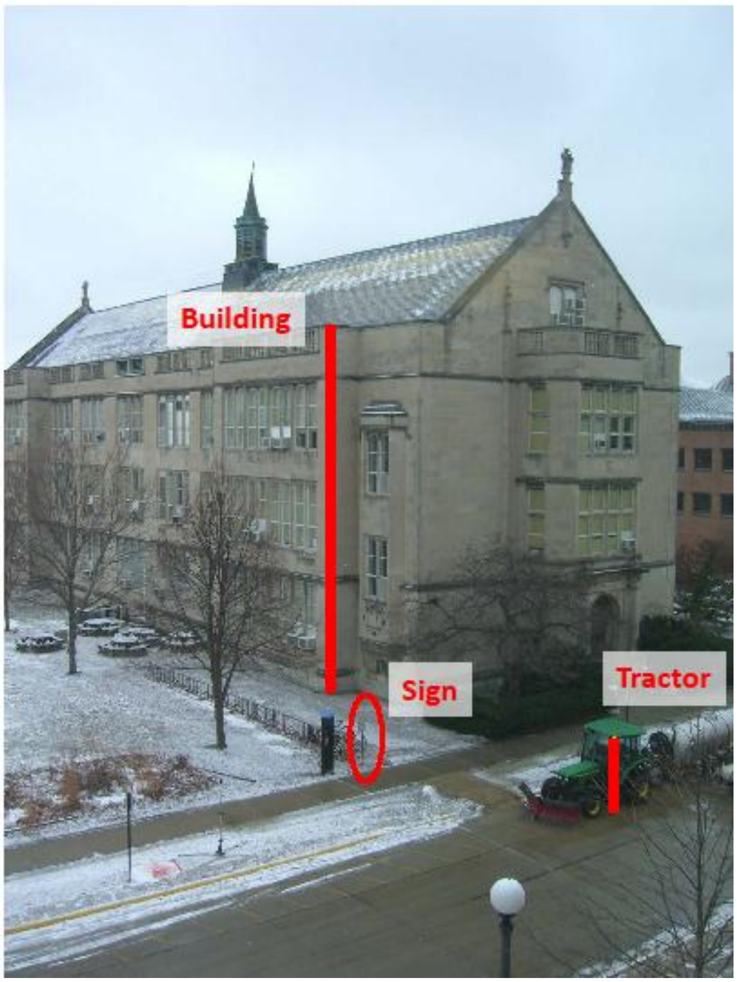
1. Single-View Metrology (40%)

A. For the Kyoto Street image, shown above, estimate the positions (in the image plane) of the three major orthogonal vanishing points (VPs), corresponding to the building orientations. Use at least three manually selected lines to solve for each vanishing point. The included code getVanishingPoint_shell provides an interface for selecting and drawing the lines, but the code for computing the vanishing point needs to be inserted.

- Plot the VPs and the lines used to estimate them on the image plane. (3%)
- Specify the VPs (u,v). (2%)
- Plot the ground horizon line and specify its parameters in the form au + bv + c = 0. Normalize the parameters so that: $a^2 + b^2 = 1$. (5%)

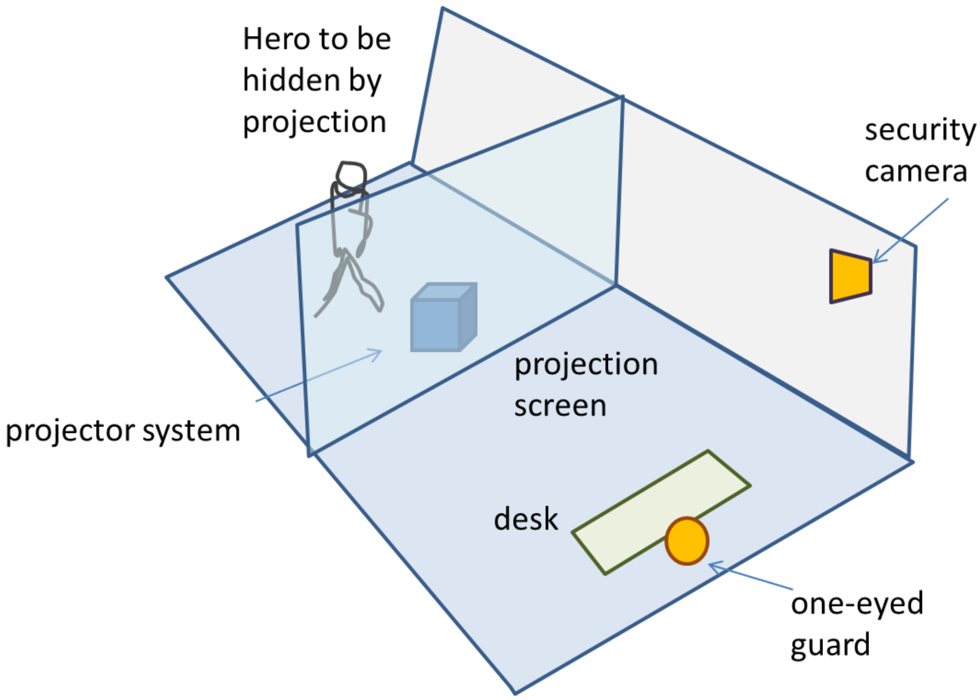
B. Use the fact that the vanishing points are in orthogonal directions to estimate the camera focal length (f) and optical center (u_0, v_0). Show all work. (10%)

C. Show how to compute the camera's rotation matrix when provided with vanishing points in the X, Y, and Z directions. (5%)
   Now, compute the rotation matrix for this image, setting the vertical vanishing point as the Y-direction, the right-most vanishing point as the X-direction, and the left-most vanishing point as the Z-direction. (5%)



D. The above photo is of the University High building, taken from the third floor in Siebel Center facing south. Estimate the horizon and draw/plot it on the image. Assume that the sign is 1.65m. Estimate the heights of the tractor, the building, and the camera (in meters). This can be done with powerpoint, paper and a ruler, or Matlab.
   - Turn in an illustration that shows the horizon line, and the lines and measurements used to estimate the heights of the building, tractor, and camera. (5%)
   - Report the estimated heights of the building, tractor, and camera. (5%)

2. Mission Possible? (10 pts)



In “Mission Impossible: Ghost Protocol”, the heroes need to work in a corridor within full view of a security guard. Their solution: erect a back-lit projection screen and project an empty hallway onto it. Assume they have ultra-super-duper projector and computer vision technology – they can update the projected image in real-time and detect/track objects. Consider the following scenarios:

a) A security camera is looking down the hallway at the screen. The camera can freely rotate but cannot otherwise move. Is it possible to put an image on the projection screen, such that the screen is undetectable for someone monitoring the camera? If not, why not? If so, what information is required? (4 pts)

b) A security guard is sitting behind his desk looking down the hallway. Recently, while inspecting a pencil, the guard poked his eye, and now he has a patch covering that eye. But he can still move around and has one good eye. Is it possible to fool the security guard? If not, why not? If so, what information is required? (3 pts)

c) Is it possible to fool both the security camera and the one-eyed security man at the same time? If not, why not? If so, what information is required? (3 pts)

Note: these should be short answers. One or two sentences is fine.

3. Epipolar Geometry (20 pts)

For the given pair of chapel images (above):

a) Use the set of matched points provided to you in prob3.mat to estimate the fundamental matrix *F* automatically using RANSAC and the normalized 8-point algorithm. (15 pts)
   - Indicate what test you used for deciding inlier vs. outlier.
   - Display F after normalizing to unit length.
   - Plot the outliers with green dots on top of the first image (plot(x, y, ‘g.’)).

b) Choose 7 sets of matching points that are well separated (can be randomly chosen). Plot the corresponding epipolar lines (‘g’) and the points (with ‘r+’) on each image. Show the two images (with plotted points and lines) next to each other. (5 pts)

The file prob3.mat has detected Harris corners row-column positions in variables *r1 c1* for the first image; variables *r2 c2* for the second image; and the corresponding matched pairs in the variable *matches*. For part (a), you may want to use the provided function plotmatches.m (e.g. `plotmatches(im1,im2,[c1 r1]’,[c2 r2]’,matches’)`) to plot matches for debugging.

Tips:

- I strongly suggest manually selecting a set of good matches and getting it working with those matches first. Then, you can get it working using RANSAC. If you get it working with manual selection but not with RANSAC, you will get half credit for part (a).
- At the very least, your epipolar lines should pass very near (e.g., within 1 pixel) your plotted points, but the solution might vary slightly from run to run.
- Consider your outlier criterion carefully.

4. Affine Structure from Motion (30%)

This problem continues the interest point detection and tracking problem from HW2. Now, you will recover a 3D pointcloud from the image sequence `hotel.seq0.png` ... `hotel.seq50.png`. You are encouraged to use your results from HW2, but in case you were not able to complete it, we have also included pre-computed intermediate results in the supplemental material. **As before, you must submit your code. Please also include pseudocode in your report.** Furthermore, do not use existing structure from motion code, such as found in OpenCV.

Use the discovered tracks found in HW2 P1.2 as input for the affine structure from motion procedure described in *Shape and Motion from Image Streams under Orthography: a Factorization Method* 1992 by Tomasi and Kanade (see section 3.4 for an overview of the algorithm).

Note that there should be a sufficient number of tracks that persist throughout the sequence to perform the factorization on a dense matrix. There is no need to fill in missing data for this problem.

To eliminate the affine ambiguity (i.e. apply the metric constraints) by discovering QQ^T (eq. 16 of Tomasi and Kanade), let $L = QQ^T$ and solve for L using least squares. Note that $\hat{\mathbf{i}}_f, \hat{\mathbf{j}}_f$ refer to rows of $\hat{R}$. Finally, compute the Cholesky decomposition of $L = QQ^T$ to recover the appropriate Q.

Required Output:

1. Plot the predicted 3D locations of the tracked points for 3 different viewpoints. Choose the viewpoints so that the 3D structure is clearly visible.

2. Plot the predicted 3D path of the cameras. The camera position for each frame is given by the cross product $\hat{\mathbf{k}}_f = \hat{\mathbf{i}}_f \times \hat{\mathbf{j}}_f$. For consistent results, normalize all $\hat{\mathbf{k}}_f$ to be the same length (i.e. unit vectors). Give 3 plots, one for each dimension of $\hat{\mathbf{k}}_f$.

Useful functions:

`svd`, `chol`

`plot3` - for plotting 3D points

References:

Tomasi and Kanade. *Shape and Motion from Image Streams under Orthography: a Factorization Method.* 1992

Extra Problems (optional)

Any of the following extensions can be done for extra credit. Points from up to two problems (up to 30 pts) will be awarded.

Shi-Tomasi Affine Verification (15 pts) Use the Shi-Tomasi approach to infer the affine transformation between each keypoint from the first frame and frames $F = [10, 20, 30, 40, 50]$. Plot the points whose appearance drifts too far over time. Also plot the unrectified and affine-rectified patches for several points for each frame in F.

Missing Track Completion (15 pts) Some keypoints will fall out of frame, or come into frame throughout the sequence. Use the matrix factorization to fill in the missing data and visualize the predicted positions of points that aren't visible in a particular frame.

Optical Flow (15 pts) Implement the optical flow approach from lecture to estimate the translation at every point. Use convolution to compute sums over W efficiently.

Coarse to Fine Tracking (15 pts) Implement the coarse-to-fine tracking procedure. To test the accuracy on large translations, tracks the keypoints by only using frames $F = [0, 10, 20, 30, 4050]$. Compare this to if you run original tracker over frames F.