Georgia Institute of Technology
George W. Woodruff School of Mechanical Engineering
ME6406 Machine Vision (Fall 2017)
Assignment #3: Due **Thursday Nov. 9, 2017**

Instruction: Solution should be in **electronic** format, either as a single MS-Word file or pdf file. This solution file should include any derivations, equations, results, figures and discussions. Put this solution file and all m-files into one single zipped file and submit electronically through T-Square. A confirmation email will be sent upon receipt of submission.

1. Camera Model and Calibration

a) Camera Model. Write a program (CameraModel.m) to transform the image '*' (represented by 20 feature points in table 1) from the 3D world coordinate ($X_w Y_w Z_w$) to the 2D undistorted image coordinate (uv) (Fig. 1). Use [$\mathbf{R}_x$(135°)], $\mathbf{T}$=[3 3.5 7.5]^T, f=1.3 to illustrate your solutions. Determine and show these 20 feature points in the uv plane. Save the (X_w, Y_w) and (u, v) values in camera_calibration_data.mat for b).

b) Camera Calibration. Write a program (CameraCalibration.m) to calibrate compute f, [$\mathbf{R}$], $\mathbf{T}$. Given the above data in camera_calibration_data.mat. Compute f, [$\mathbf{R}$], $\mathbf{T}$.

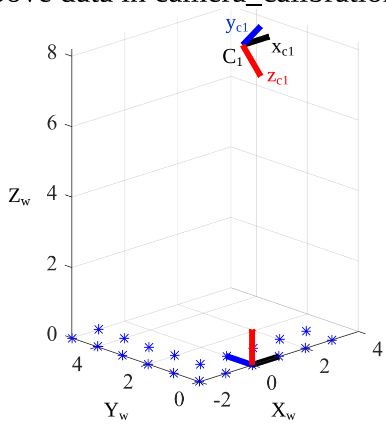

Fig. 1 Camera model and calibration

Table 1 Camera calibration points

X_w	-2	-1	0	1	2
Y_w	0	0	0	0	0
Z_w	0	0	0	0	0
X_w	3	-2	-1	0	1
Y_w	0	1	1	1	1
Z_w	0	0	0	0	0
X_w	2	3	-1	-2	-1
Y_w	1	1	2	2	3
Z_w	0	0	0	0	0
X_w	-2	-1	-2	-1	-2
Y_w	3	4	4	5	5
Z_w	0	0	0	0	0

2. Robot Eye-on-Hand Calibration

Fig. 2a shows the setup for performing an eye-on-hand calibration where a stationary planar calibration board is viewed at 3 different locations by a camera mounted on a robot gripper. Fig. 2b shows the images in three camera image planes. The transformation matrices from CW to C_i can be determined by the camera calibration ([$\mathbf{H}_{ci}$] where i=1, 2, 3). The rigid body transformations of the robot gripper from Station 1 to 2 and 2 to 3 ([$\mathbf{H}_{g12}$] and [$\mathbf{H}_{g23}$]) are given by the robot controller. Write a MATLAB program for the eye-an-hand calibration. Using the given ([$\mathbf{H}_{c1}$] [$\mathbf{H}_{c2}$] [$\mathbf{H}_{c3}$]) data in '*robot_hand_eye_data.mat*' to illustrate your solutions:

1) Compute ([$\mathbf{R}_{c12}$], $\mathbf{T}_{c12}$) and ([$\mathbf{R}_{c23}$], $\mathbf{T}_{c23}$).

2) Obtain the equivalent angle-axis representation (n, θ) for each of the rotation matrixes; [$\mathbf{R}_{c12}$], [$\mathbf{R}_{c23}$], [$\mathbf{R}_{g12}$] and [$\mathbf{R}_{g23}$].

3) Compute P_{c12}, P_{c23}, P_{g12} and P_{g23}. Check your solutions by computing [$\mathbf{R}_{g12}$] and [$\mathbf{R}_{g23}$] using Equations (8) and (10) in [2] and comparing with those given in the data file '*robot_hand_eye_data.mat*'.

4) Use the procedure in [2] to compute $\mathbf{P}_{cg}$, [$\mathbf{R}_{cg}$] and $\mathbf{T}_{cg}$.

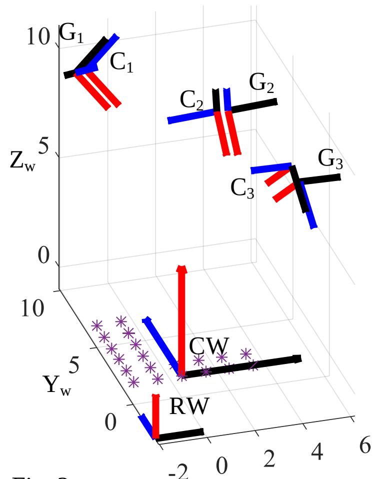

Fig. 2a

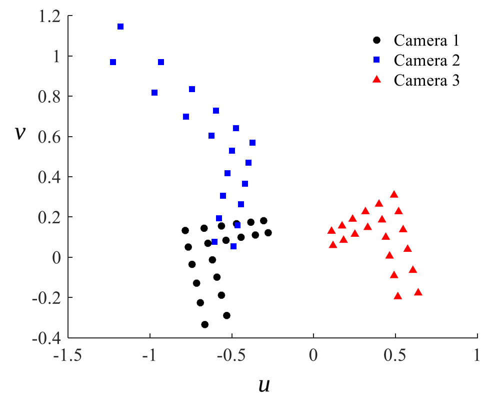

Fig. 2b

3. Ellipse-Circle Correspondence

Using a least squares fit, a circle captured by a camera (with focal length f=0.1) in the image frame has the following ellipse equation, $(x-1)^2/4+(y-1)^2/16=1$. By transforming the equation to the standard conic form and if the radius of the circle is 1, find the plane equation (with respect to the camera frame) that contains the circle. Where is the center of the circle with respect to the camera frame?

References:

[1] Tsai, R. "A Versatile Camera Calibration Technique for High-accuracy 3D Machine Vision Metrology using Off-the-shelf TV Cameras and Lenses," *IEEE Trans. on Robotics and Automation*, Vol. 3, No.4, pp. 323- 344, 1987.

[2] Tsai, R.Y. and R.K. Lenz, "A New Technique for Fully Autonomous and Efficient 3D Robotics Hand/Eye Calibration," *IEEE Trans. on Robotics and Automation*, Vol. 5, No. 3, 1989.

[3] Qiang Ji, Mauro Costa, Robert Haralick, and Linda Shapiro, "An Integrated Linear Technique for Pose Estimation from Different Features," *International Journal of Pattern Recognition and Artificial Intelligence*, Vol. 13, No. 5, 1999.