Georgia Institute of Technology
George W. Woodruff School of Mechanical Engineering
ME6406 Machine Vision (Fall 2021)
Assignment #3: (ME6406A Due **Wednesday November 3rd 2021, 23:59pm EDT**)

All programs should be written using MATLAB. Solutions must be consolidated into a **single pdf file** (including all results and an explanation of results) and a **zip file** (including all m-files used for the results). Solutions must be submitted electronically through **Canvas**. Late solutions will be penalized at 10% deduction from the homework score, and will NOT be accepted 24 hours after due date.

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 ($X_wY_wZ_w$) 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 the camera. Using the above data saved in camera_calibration_data.mat. Compute f, [$\mathbf{R}$], $\mathbf{T}$.

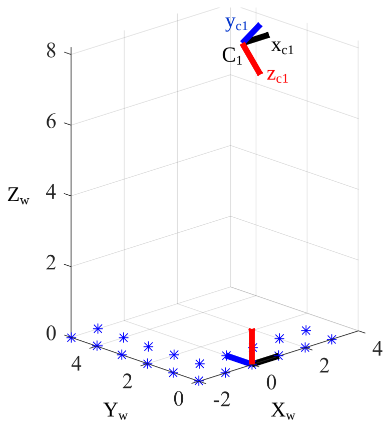

Fig. 1 Camera model and calibration

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:

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

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

c) 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*'.

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

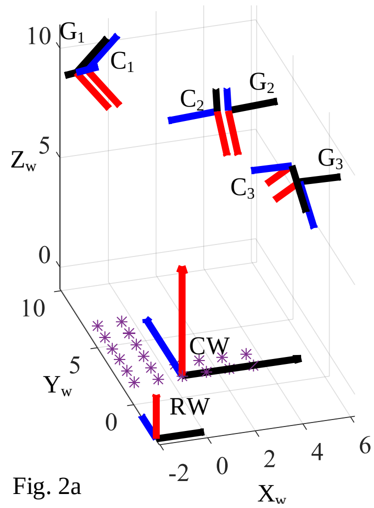

Fig. 2a

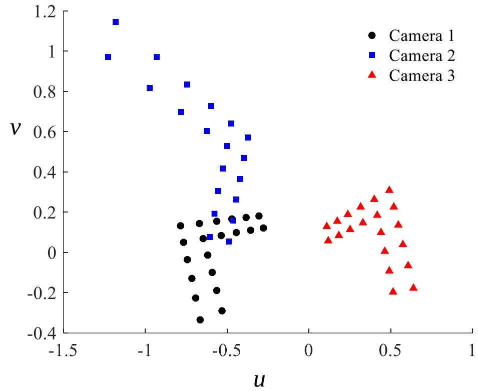

Fig. 2b

3. Ellipse-Circle Correspondence

   A circle captured by a camera (with focal length f=0.8690cm) in the image plane has the following general ellipse equation, $Au^2 + 2Buv + Cv^2 + 2Du + 2Ev + F = 0$. The coefficients are given in file 'coef2021.mat', and the circle radius r = 6.5cm. Where is the center of the circle with respect to the camera frame? Find the plane equation (with respect to the camera frame) that contains the circle. (Without additional information, multiple solutions are possible. Find all valid solutions).

4. Morphology

   Use the following steps and the structure element in Fig.3b to denoise the 'Fingerprint.jpg' image.

   - AΘB
   - (AΘB)⊕B
   - [(AΘB)⊕B] ⊕B
   - {[(AΘB)⊕B] ⊕B}ΘB

   Show the corresponding images obtained after all 4 operations.

Fig. 3a

1	1	1
1	1	1
1	1	1

Fig. 3b

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.