Georgia Institute of Technology
George W. Woodruff School of Mechanical Engineering
ME6406 Machine Vision (Fall 2016)
Assignment #4 due December 1, 2016 (Thursday)

## 1. Stereo Vision and Pose Estimation

(a) Camera Model. Write a program (CameraModel.m) to transform 8 features image -points indicated as "∗" in Fig. 1 from the 3D world coordinate ($X_wY_wZ_w$) to the 2D undistorted image coordinate ($u_1v_1$, $u_2v_2$) for Camera+ and Camera– (both with the same length $f$=1.2), the coordinates of which are defined by

Camera ±: Start with $[\mathbf{R}_x(180°)]$ and $\mathbf{T}=[\pm 2\ 0.5\ 8]^T$, then $[\mathbf{R}_y(\mp 30°)]$.

Given the location/orientation of the two cameras and the 8 physical points (Table 1), determine and show the same points but in the corresponding image planes ($u_1v_1$, $u_2v_2$).

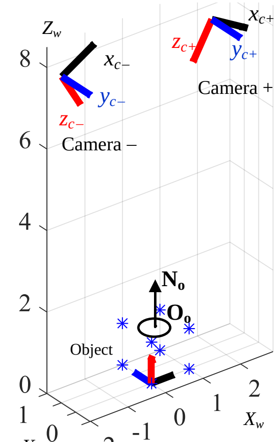

Fig. 1

Table 1 Features

| | Eight feature points | | | | | | | | $O_o$ | $N_o$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $X_w$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0.5 | 0 |
| $Y_w$ | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0.5 | 0 |
| $Z_w$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

(b) Stereo Vision. Using the computed image points in Part (a), write a program (StereoVision.m) to reconstruct the 8 physical feature points in the world coordinates.

(c) Pose Estimation [1]. Write a program (PoseEstimation.m) to calculate the rotation matrix **R** and translation vector **T** from the world coordinates to Camera +. You may use the following steps:

Step 1: Determine these 8 feature points and the centroid and normal vectors of the circle (Table 1) in Camera + coordinates.

Step 2: Form the matrix $[\mathbf{W}]=[\mathbf{M}\ \ \mathbf{Q}\ \ \mathbf{Q}']^T$ to solve for **V** (that contains the elements of **R** and **T**) from $[\mathbf{W}]\mathbf{V}=\mathbf{b}$, where **M** and **Q** characterize the point and the ellipse-circle correspondences; and **Q'** takes into account the orthonormal constraints.

## 2. Neural Network [2]

Design an artificial neural network (ANN) based on back-propagation learning for number recognition. To illustrate your understanding, the ANN is designed to have 49 inputs and 4 outputs to recognize the numerical characters (1, 2, 3 and 4) in a binary 7x7 image.

(a) Derive the weight-update rule for the ANN assuming that each of the processing elements has a uni-polar sigmoid function.

(b) Write a Matlab program NN_training.m to train the ANN using the training patterns in training_data.m (Fig. 2a). Show the convergence curve (mean squared error vs. number of epoch). Save the weights of nodes in the file NN_weights.mat.

(c) Write a Matlab program NN_test.m (that reads the weights of nodes in NN_weights.mat) to test the ANN using data in test_data.m (Fig. 2b). Show the values of four output nodes for each testing pattern.

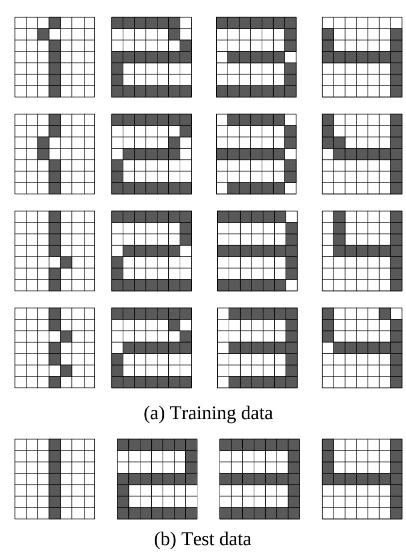

Fig 2. Patterns

## 3. Color

**Artificial Color Contrast (ACC) [3]** increases color contrast using the DoG functions to facilitate feature classification as discussed in class:

$$h_i(x,y) = G_{\sigma c} * f_j(x,y) - G_{\sigma s} * f_k(x,y)$$

Derive $h_i(x,y)$ with $f_j(x,y) = R(x,y)$ and $f_k(x,y) = -[R(x,y) - G(x,y)]$ where $R(x,y)$ and $G(x,y)$ correspond to the red and green component images respectively. Use this single channel to filter out blood stains and find the fanbone in the image '*fanbone.bmp*' (Fig. 3).

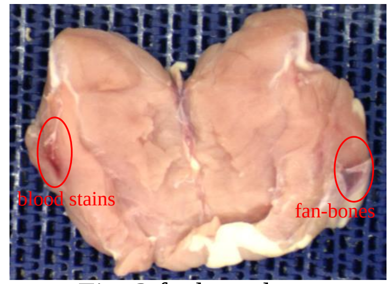

Fig. 3 fanbone.bmp

**Principle component analysis (PCA):** Use the RGB image '*fanbone.bmp*' for the following.

(a) Determine the covariance matrix of data.
(b) Derive the components (eigenvectors) with eigenvalues arranged in a descending order.
(c) Obtain the maximum and minimum values of three component matrices. Show these three matrices (images) with linear mapping from the minimum and maximum values to the range of (0-255).

**Color-based Image Segmentation:** Color is an important information. Same objects commonly have their domain color. *L-a-b* color system is the color-opponent space with the *L* lightness dimension and *a-b* color-opponent dimensions. The color-based image segmentation can be performed by applying the clustering method on the points in *a-b* domain. Transfer pixels from *RGB* to *Lab* color system and followed by applying *k-means* clustering on data in *a-b* domain with cluster number ($k$=3) for segmentation of the *RGB* image '*fanbone.bmp*'.

## 4. Morphology

(a) As in the case of dilation and erosion, opening and closing are duals of each other with respect to set complementation and reflection. Prove validity of the duality expression: $(\mathbf{A} \bullet \mathbf{B})^c = (\mathbf{A}^c \circ \hat{\mathbf{B}})$

(b) Write a MATLAB program to perform a morphological filtering on the head CT image in Fig. 4(a) using the structuring element in Fig. 4(b). Denoting the head CT image as $f$ and the structuring element as $b$, perform morphological gradient operation on $f$ by following the steps:

- $f \oplus b$
- $f \ominus b$
- $(f \oplus b) - (f \ominus b)$

Show the corresponding image obtained in each step


Fig. 4(a)

| | | |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 1 | 1 |
| 1 | 1 | 1 |

Fig. 4(b)

Suggested MATLAB function: *imdilate.m*, *imerode.m*

**Reference:**

[1] 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

[2] Simpson, P. (1992). Foundations of neural networks, Chapter 1 in *Artificial Neural Networks*, Lau, C. & Sanchez-Sinencio, E. (Eds.), pp. 2-13, IEEE Press, New York, NY

[3] Lee, K.-M.; Li, Q.; Daley, W, "Effects of Classification Methods on Color-Based Feature Detection With Food Processing Applications," *IEEE Trans. on Automation Science and Engineering*. Vol. 4, No. 1, Jan. 2007 pages: 40-51