Assignment 9

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The link to the solution is

https://github.com/Adarsh1310/EE5609

***Abstract*—This documents solves a Singular Value decomposition problem.**

1 Problem

Find the shortest distance between the lines

$$\mathbf{x} = \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} + \lambda_1 \begin{pmatrix} 2 \\ -1 \\ 1 \end{pmatrix} \tag{1.0.1}$$

$$\mathbf{x} = \begin{pmatrix} 2 \\ 1 \\ -1 \end{pmatrix} + \lambda_2 \begin{pmatrix} 3 \\ -5 \\ 2 \end{pmatrix} \tag{1.0.2}$$

2 Solution

The lines will intersect if

$$\begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} + \lambda_1 \begin{pmatrix} 2 \\ -1 \\ 1 \end{pmatrix} = \begin{pmatrix} 2 \\ 1 \\ -1 \end{pmatrix} + \lambda_2 \begin{pmatrix} 3 \\ -5 \\ 2 \end{pmatrix} \tag{2.0.1}$$

$$\begin{pmatrix} 2 & 3 \\ -1 & -5 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ -1 \end{pmatrix} \tag{2.0.2}$$

$$\mathbf{A}\lambda = \mathbf{b} \tag{2.0.3}$$

Since the rank of augmented matrix will be 3. We can say that lines do not intersect.

$$\mathbf{A} = \mathbf{USV}^T \tag{2.0.4}$$

Where the columns of $\mathbf{V}$ are the eigenvectors of $\mathbf{A}^T\mathbf{A}$,the columns of $\mathbf{U}$ are the eigenvectors of $\mathbf{AA}^T$ and $\mathbf{S}$ is diagonal matrix of singular value of eigenvalues of $\mathbf{A}^T\mathbf{A}$.

$$\mathbf{A}^T\mathbf{A} = \begin{pmatrix} 6 & 13 \\ 13 & 38 \end{pmatrix} \tag{2.0.5}$$

$$\mathbf{AA}^T = \begin{pmatrix} 13 & -17 & 8 \\ -17 & 26 & -11 \\ 8 & -11 & 5 \end{pmatrix} \tag{2.0.6}$$

Eigen vectors of $\mathbf{A}^T$A.

$$\begin{vmatrix} 6-\lambda & 13 \\ 13 & 38-\lambda \end{vmatrix} \lambda^2 - 44\lambda + 59 = 0 \tag{2.0.7}$$

$$\lambda_1 = -5\sqrt{17} + 22, \lambda_2 = 5\sqrt{17} + 22 \tag{2.0.8}$$

Hence,The eigenvectors will be

$$\mathbf{v}_1 = \begin{pmatrix} \frac{5\sqrt{17}-16}{13} \\ 1 \end{pmatrix}, \mathbf{v}_2 = \begin{pmatrix} \frac{-5\sqrt{17}-16}{13} \\ 1 \end{pmatrix} \tag{2.0.9}$$

Normalising the eigenvectors

$$l_1 = \sqrt{\left(\frac{5\sqrt{17}-16}{13}\right)^2 + 1^2} = \frac{\sqrt{850-160\sqrt{17}}}{13} \tag{2.0.10}$$

$$\mathbf{v}_1 = \frac{13}{\sqrt{850-160\sqrt{17}}} \begin{pmatrix} \frac{5\sqrt{17}-16}{13} \\ 1 \end{pmatrix} \tag{2.0.11}$$

$$\mathbf{v}_1 = \begin{pmatrix} \frac{5\sqrt{17}-16}{\sqrt{850-160\sqrt{17}}} \\ \frac{13}{\sqrt{850-160\sqrt{17}}} \end{pmatrix} \tag{2.0.12}$$

$$l_2 = \sqrt{\left(\frac{-5\sqrt{17}-16}{13}\right)^2 + 1^2} = \frac{\sqrt{850+160\sqrt{17}}}{13} \tag{2.0.13}$$

$$\mathbf{v}_2 = \frac{13}{\sqrt{850+160\sqrt{17}}} \begin{pmatrix} \frac{-5\sqrt{17}-16}{13} \\ 1 \end{pmatrix} \tag{2.0.14}$$

$$\mathbf{v}_2 = \begin{pmatrix} \frac{-5\sqrt{17}-16}{\sqrt{850+160\sqrt{17}}} \\ \frac{13}{\sqrt{850+160\sqrt{17}}} \end{pmatrix} \tag{2.0.15}$$

From here we can say that

$$\mathbf{V} = \begin{pmatrix} \frac{5\sqrt{17}-16}{\sqrt{850-160\sqrt{17}}} & \frac{-5\sqrt{17}-16}{\sqrt{850+160\sqrt{17}}} \\ \frac{13}{\sqrt{850-160\sqrt{17}}} & \frac{13}{\sqrt{850+160\sqrt{17}}} \end{pmatrix} \tag{2.0.16}$$

Eigen vectors of $\mathbf{AA}^T$.

$$\begin{vmatrix} 13-\lambda & -17 & 8 \\ 17 & 26-\lambda & -11 \\ 8 & -11 & 5-\lambda \end{vmatrix} - \lambda^3 + 44\lambda^2 - 59\lambda = 0 \tag{2.0.17}$$

$$\lambda_2 = -5\sqrt{17} + 22, \lambda_1 = 5\sqrt{17} + 22, \lambda_3 = 0, \tag{2.0.18}$$

Hence,The eigenvectors will be

$$\mathbf{u}_2 = \begin{pmatrix} \frac{\sqrt{17}+12}{5} \\ \frac{3\sqrt{17}+1}{5} \\ 1 \end{pmatrix} \mathbf{u}_1 = \begin{pmatrix} \frac{-\sqrt{17}+12}{5} \\ \frac{-3\sqrt{17}+1}{5} \\ 1 \end{pmatrix} \mathbf{u}_3 = \begin{pmatrix} \frac{-3}{7} \\ \frac{1}{7} \\ 1 \end{pmatrix} \tag{2.0.19}$$

Normalising the eigenvectors

$$l_1 = \sqrt{\left(\frac{12-\sqrt{17}}{5}\right)^2 + \left(\frac{1-3\sqrt{17}}{5}\right)^2 + 1^2} \tag{2.0.20}$$

$$\mathbf{u}_1 = \begin{pmatrix} \frac{-\sqrt{17}+12}{\sqrt{340-20\sqrt{17}}} \\ \frac{-3\sqrt{17}+1}{\sqrt{340-20\sqrt{17}}} \\ \frac{5}{\sqrt{340-20\sqrt{17}}} \end{pmatrix} \tag{2.0.21}$$

$$\tag{2.0.22}$$

$$l_2 = \sqrt{\left(\frac{\sqrt{17}+12}{5}\right)^2 + \left(\frac{3\sqrt{17}+1}{5}\right)^2 + 1^2} \tag{2.0.23}$$

$$\mathbf{u}_2 = \frac{5}{\sqrt{340+20\sqrt{7}}} \begin{pmatrix} \frac{\sqrt{17}+12}{5} \\ \frac{3\sqrt{17}+1}{5} \\ 1 \end{pmatrix} \tag{2.0.24}$$

$$\mathbf{u}_2 = \begin{pmatrix} \frac{\sqrt{17}+12}{\sqrt{340+20\sqrt{17}}} \\ \frac{3\sqrt{17}+1}{\sqrt{340+20\sqrt{17}}} \\ \frac{5}{\sqrt{340+20\sqrt{17}}} \end{pmatrix} \tag{2.0.25}$$

$$l_3 = \sqrt{\left(\frac{-3}{7}\right)^2 + \left(\frac{1}{7}\right)^2 + 1^2} \tag{2.0.26}$$

$$\mathbf{u}_3 = \frac{7}{\sqrt{59}} \begin{pmatrix} \frac{-3}{7} \\ \frac{1}{7} \end{pmatrix} \tag{2.0.27}$$

$$\mathbf{u}_3 = \begin{pmatrix} \frac{-3}{\sqrt{59}} \\ \frac{1}{\sqrt{59}} \\ \frac{7}{\sqrt{59}} \\ \frac{7}{\sqrt{59}} \end{pmatrix} \tag{2.0.28}$$

$$\mathbf{U} = \begin{pmatrix} \frac{-\sqrt{17}+12}{\sqrt{340-20\sqrt{17}}} & \frac{\sqrt{17}+12}{\sqrt{340+20\sqrt{17}}} & \frac{-3}{\sqrt{59}} \\ \frac{-3\sqrt{17}+1}{\sqrt{340-20\sqrt{17}}} & \frac{3\sqrt{17}+1}{\sqrt{340+20\sqrt{17}}} & \frac{1}{\sqrt{59}} \\ \frac{7}{\sqrt{59}} & & \\ \frac{5}{\sqrt{340-20\sqrt{17}}} & \frac{5}{\sqrt{340+20\sqrt{17}}} & \frac{7}{\sqrt{59}} \end{pmatrix} \tag{2.0.29}$$

Now,

$$\mathbf{S} = \begin{pmatrix} \sqrt{5\sqrt{17}+22} & 0 \\ 0 & \sqrt{-5\sqrt{17}+22} \\ 0 & 0 \end{pmatrix} \tag{2.0.30}$$

So,from equation (2.0.4)

$$\begin{pmatrix} 2 & 3 \\ -1 & -5 \\ 1 & 2 \end{pmatrix} = \begin{pmatrix} \frac{-\sqrt{17}+12}{\sqrt{340-20\sqrt{17}}} & \frac{\sqrt{17}+12}{\sqrt{340+20\sqrt{17}}} & \frac{-3}{\sqrt{59}} \\ \frac{-3\sqrt{17}+1}{\sqrt{340-20\sqrt{17}}} & \frac{3\sqrt{17}+1}{\sqrt{340+20\sqrt{17}}} & \frac{1}{\sqrt{59}} \\ \frac{7}{\sqrt{59}} & & \\ \frac{5}{\sqrt{340-20\sqrt{17}}} & \frac{5}{\sqrt{340+20\sqrt{17}}} & \frac{7}{\sqrt{59}} \end{pmatrix} \begin{pmatrix} \sqrt{5\sqrt{17}+22} & 0 \\ 0 & \sqrt{-5\sqrt{17}+22} \\ 0 & 0 \end{pmatrix} \begin{pmatrix} \frac{5\sqrt{17}-16}{\sqrt{850-160\sqrt{17}}} & \frac{-5\sqrt{17}-16}{\sqrt{850+160\sqrt{17}}} \\ \frac{13}{\sqrt{850-160\sqrt{17}}} & \frac{13}{\sqrt{850+160\sqrt{17}}} \end{pmatrix}^T \tag{2.0.31}$$

Now, Finding Moore-Penrose Pseudo inverse of S

$$\mathbf{S}_+ = \begin{pmatrix} \frac{1}{\sqrt{5\sqrt{17}+22}} & 0 & 0 \\ 0 & \frac{1}{\sqrt{-5\sqrt{17}+22}} & 0 \end{pmatrix} \tag{2.0.32}$$

We will use this Pseudo inverse to find the solution

$$\lambda = \mathbf{V}(\mathbf{S}_+(\mathbf{U}^T\mathbf{b}) \tag{2.0.33}$$

$$= \begin{pmatrix} 0.42 \\ -0.11 \end{pmatrix} \tag{2.0.34}$$