

Grading of Dysplastic Stages of Cervical Tissue through PCA Analysis of Mueller Decomposed Images

Prashant Shukla

Dr. H. S. Gour University, Sagar

Email: opticsshukla@gmail.com

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Abstract: Here we report the results derived from principal component analysis (PCA) of Mueller decomposed images of cervical tissues. PCA multivariate analysis, depolarization power data is reduced to a few important components well suited for diagnostic purpose. The subtle changes in the polarization property of the tissue medium, with the progression of dysplasia, are found to be well captured by the second and third principal components of the covariance matrix, which clearly differentiate the normal and diseased tissues. Interestingly, the principal components are found to be sensitive enough to discriminate between two different stages of dysplastic conditions. Hence, PCA technique allows automated diagnosis that enhances the potential of real-time clinical detection of disease.

1. Introduction

In a recent past optical spectroscopic techniques emerge as powerful diagnostic tools. Among spectroscopic techniques fluorescence and Raman techniques are widely used for studying the biochemical changes during the progression of disease. To make spectroscopic techniques like fluorescence, Raman etc. more efficient for diagnostic purpose several groups¹⁻¹⁴ have used principal component analysis (PCA).

Principal component analysis (PCA) is multivariate analysis, which allows dimensional reduction. Using PCA technique on fluorescence spectra, several researchers¹⁻⁶ have shown that discrimination can be made between normal, benign and malignant tissues more accurately. In addition to this several groups have reported the discrimination between normal and cancer stages through PCA analysis on Raman data of various tissues⁷⁻¹⁴. The efficacy of PCA analysis for various spectroscopy have shown, that it can be a robust and user – friendly technique, and helpful in discriminating normal and cancer tissues more accurately.

Motivating with this we have applied PCA approach on Mueller decomposed images of normal and dysplastic tissues of same patients. A systematic study is carried out on individual patient's data to identify suitable parameters and check their sensitivity in all patients. It was observed that PCA technique has a potential in deciding the grades of dysplasia.

2. Experimental Setup

Experiments have been done in the transmission mode for generating Mueller decomposition Images. Samples were illuminated with He-Ne laser (Melles Griot, 20mW, $\lambda = 632.8$ nm) having spot size of 1.1 mm. Mueller images of these tissue slides were recorded on a CCD (Apogee 1E, USA) having resolution of 768 x 512 pixels. The incident beam was polarized using a linear polarizer (Glan Thompson having extinction coefficient 100000:1) placed between the sample and the source. The transmitted light from the sample was collected by a convex lens and after passing through subsequent polarization optics, was made to fall on the CCD. This experimentally obtained matrix was then subjected to Mueller decomposition¹⁵ to extract diattenuation, retardance and depolarization power for the spot captured in the CCD.

According to the polar decomposition algorithm, any Mueller matrix M can be decomposed into three elementary matrices representing a depolarizer (M_{Δ}), a retarder (M_R) and a diattenuator (M_D) as¹⁵

$$M = M_{\Delta} M_R M_D.$$

The depolarizing matrix M_{Δ} accounts for the depolarizing effects of the medium, the retarder matrix M_R describes the effects of linear birefringence and optical activity, and the diattenuator matrix M_D includes the effects of linear and circular dichroism.

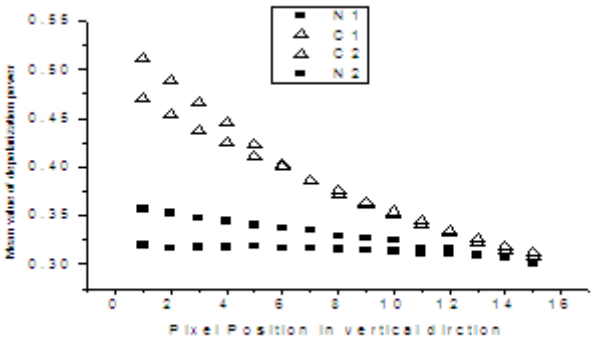
Principal component analysis (PCA) has been done over the mean values of depolarization power along pixel positions from basal to the outer region of epithelium region, over all patients, in order to identify the pixel region showing maximum discrimination. PCA analysis captures the correlation behavior for normal and dysplastic tissues separately, for all the samples' pixel to pixel position. In addition to this, the principal components provide significant directions to isolate different tissue types.

Samples used in this study were the stained cervical slides of cervical tissues prepared for histopathology. These slides contain the vertical

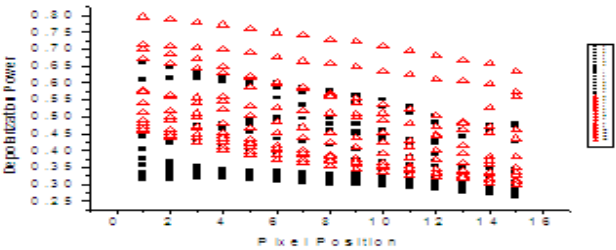
sections of tissues having thickness $5\mu\text{m}$. The lateral dimensions of tissue sections were $4\text{mm} \times 6\text{mm}$.

3. Results and Discussion

As noted from Fig. 1(a), the dysplastic tissues can be well discriminated from the normal tissues by their mean depolarization powers within the first 10 pixels. The differences are less highlighted Figure 1 shows the plot of mean values of depolarization power (taken along horizontal axis) against the pixel beyond these 10 pixels. This shows that during the progression of dysplasia, the changes in cell density are enhanced in first 10 pixels which correspond to around $100\mu\text{m}$ from vicinity of basal layer going up to the middle of the epithelium. This confirms with histopathological reports. Further, in Fig. 1(b) the same has been shown for all patients. This does not reveal as a clear discrimination as Fig. 1(a).



(a)



(b)

Fig. 1 Mean values of depolarization power along the horizontal direction of epithelium (a) normal and dysplastic states of same patients and (b) normal and dysplastic states of all patients

For identifying the pixel region representing clear demarcation between tissue types, amongst all patients, we subject the Mueller matrices to principal component analysis. Amongst the principal components the second and third ones have been found to clearly isolate the dysplastic tissues from the normal ones. Furthermore, these can differentiate two dysplastic conditions.

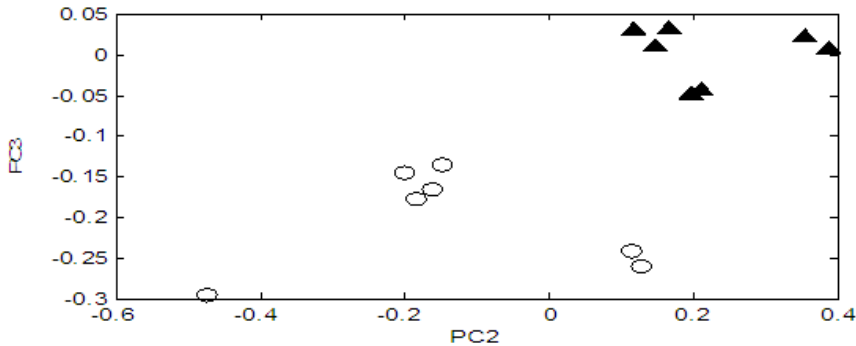


Fig. 2(a) PC3 Vs PC2 for dysplasia grade-1 ($\circ$) and their normal ($\blacktriangle$) counter parts

Figure 2(a) shows a large separation in the plot of third principal component (PC3) against the second principal component (PC2) between dysplasia grade-1 and their normal counter parts for all patients. Similar behavior is seen from the plot of PC3 against the PC2 in case of dysplasia grade-2 patients as shown in Fig. 2(b). In addition to this PC3 against PC2 analysis has been also done for dysplasia grade-2, dysplasia grade-1 and all the normal tissues combined together and displayed in Fig. 3. It can be observed from Fig.3 that there is clear demarcation among normal, dysplasia grade-1 and dysplasia grade-2.

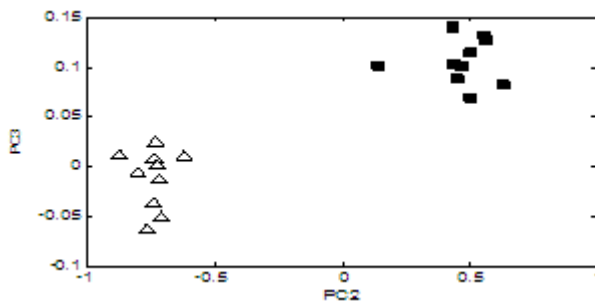


Fig. 2(b) PC3 Vs PC2 for dysplasia grade-2 ($\blacksquare$) and their normal (Δ) counter parts

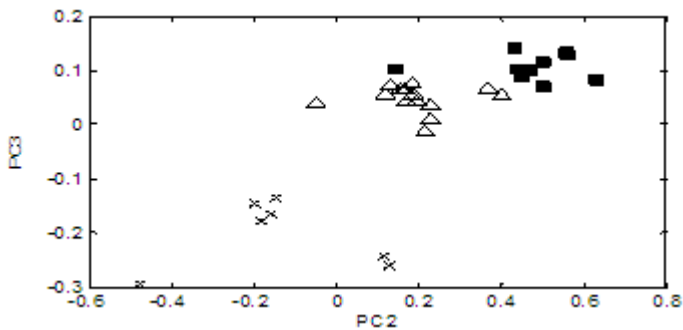


Fig. 3 PC3 Vs PC2 for dysplasia grade-1 (×), normal (Δ) and dysplasia grade-2 (■)

4. Conclusion

The principal component analysis of the depolarization power, derived from polar decomposition of Mueller matrices, of all patients clearly identifies the tissue region, from the pixel by pixel data, responsible for significant discrimination between the diseased and normal tissues. Finally the fact that three clusters seen in the PC3 versus PC2 plots show very clear demarcation indicates the sensitivity of categorizing the different stages of dysplasia efficiently. This study shows the potential of PC analysis as a powerful diagnostic technique to discriminate the different stages of dysplasia in cervical tissues. PCA technique allows automated diagnosis that enhances the potential of real-time clinical detection of disease.

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