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Estimation of the Fractal Dimension using Tiled Triangular Prism Method for Biological Non-Rectangular Objects

***Abstract**. The aim of the study is application of Triangular Prism Method (TPM) algorithm in computer assisted Papanicolaou smears analysis that is useful in cervical cancer screening. The TPM algorithm allows estimation of the FD (fractal dimension) for optical density of cell nuclei. Selection of the local FD for green color channel gives efficient separation between both cell nuclei classes. Proposed algorithm (Tiled TPM) improves separation by the fractal based estimation using larger area of the cell nuclei.*

***Streszczenie.** W artykule zaproponowano nowy algorytm estymacji wymiaru fraktalnego dla obiektów nieregularnych, takich jak jądra komórek bazujący na metodzie pryzm trójkątnych (TPM). Kafelkowy algorytm pryzm trójkątnych pozwala na estymację wymiaru fraktalnego dla większego pola powierzchni obiektu oraz pozwala na estymację lokalnych wymiarów fraktalnych dla małych skal. (**Estymacja wymiaru fraktalnego z wykorzystaniem kafelkowej metody pryzm trójkątnych dla nieprostokątnych obiektów biologicznych**)*

Keywords: pattern recognition, image processing, fractal dimension, Papanicolaou smears, cervical cancer screening
Słowa kluczowe: rozpoznawanie obrazów, przetwarzanie obrazów, rozmaz Papanicolaou, skryning w kierunku raka szyjki macicy

Introduction

Digital image analysis of cervical cytology [1] allows detection of precancerous and cancer condition. The large number of cell is required for this purpose. Special attention is paid on cell nuclei. The use of microscopes with digital camera and slide scanners allows image registration, that may be processed by automatic system for assisted classification [2,3]. This is challenging task in case of Papanicolaou (Pap) smears [4], because of high complexity in biological objects images. An example cells that have excellent separation of the cells are shown in Fig.1.

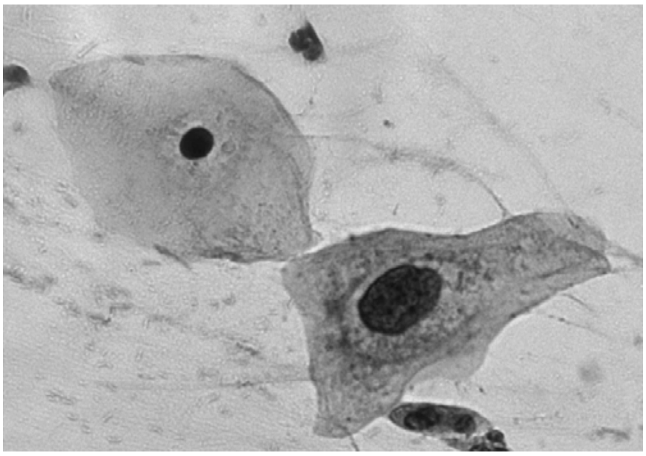

Fig.1. Example of cells (left – normal cell, right – atypical cell)

Computer assisted classification allows classification of cells for further analysis of abnormal cells by cytoscreener and pathomorphologist and should improve detection ratio and reduces screening time [2,3].

Digital image processing and pattern recognition techniques in cells nuclei images were introduced in previous century [5-8]. Fractal analysis was proposed for binary image analysis of cell nuclei for atypia detection. Box counting method is possible for processing of nucleus area after threshold operation. Measurement of fractal perimeter of cell nucleus is another approach [9]. These approaches do not consider the texture of cell nucleus directly, that is essential in process of analysis by cytoscreener. TPM algorithm (Triangular Prism Method) was proposed [10] for the estimation of FD of cell nuclei from Pap smear according to optical density. Pap smears images are color based and the most promising color channel images are the green or eventually the gray scale [10]. The solution is based on FD measurement for monochromatic images. Obtaining of single FD for cell nucleus does not allow adequate separation between classes of objects, that is desired. Estimation of few FD for few scales is necessary, because FD differs according to scale and is not one valued. Conventional fractal analysis techniques for images require square area of analysis. It is not fitted into elliptical shapes of cell nuclei. Irregular cell nuclei are common for the atypia. Proposed technique, based on the previous analysis [10] of the scale importance, uses larger area of cell nuclei in comparison to the conventional technique.

In Fig.2 are shown examples cell nuclei. They are good examples of both classes but the more complex cases occur and differences are not so well visible.

Fractal techniques, based on comparison of occupied field (box counting) or perimeter analyses, are possible. Atypical cell nuclei occupy less round area (important for box counting) and have eroded edge (important for perimeter fractal). Size of the cell nuclei is an also important factor considered during analysis but not one. Texture differences are well visible, and the correct cell nucleus has smooth texture (important for fractal dimension of the optical density).

Fig.2. Example of cells nuclei (left – normal cell nucleus, right – atypical cell nucleus) extracted and normalized from the green channel of Fig.1 (scale is preserved).

Fractal analysis of cell nuclei

TPM algorithm [11] allows estimation of FD with use of Richardson's plot [12-14]. It is based on estimation of top of prism field for 5 points (Fig.3).

Other formulation of the triangular prism are possible also (there are two cases where two triangular prism are extracted from the square region instead four). Alternative techniques for analysis of the optical density for FD are available [15] also: isarithm method, variogram estimator, probability estimator, variation estimator.

There is not available best FD estimator. Some of the estimators give larger or smaller values during the test of synthetically generated images. It is not important until single technique is used. Precised FD value is not necessary for preclassification applications.

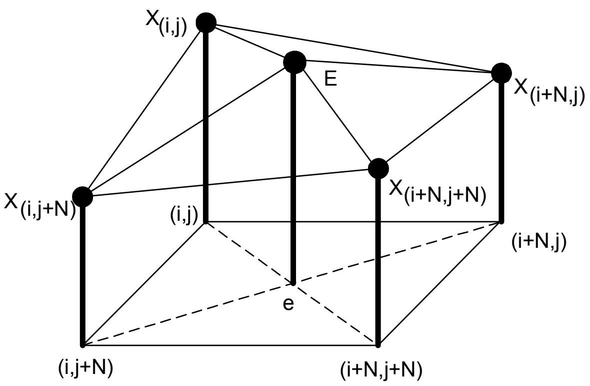

Fig.3. Triangular prism model

Original TPM algorithm [11] estimates the height value ‘E’ for fifth point ‘e’. In this paper, the value is obtained directly and the smallest area of analysis has 3x3 pixel size (it corresponds to the scale s=1). The size of area (BxB) is determined by the following formulas:

$$B = s^2 + 1 \qquad (1)$$
$$N = s^2$$

X-values are pixel values of image and the field is estimated using formula for four triangles: [X(i,j+N), X(i+N,j+N), E], [X(i+N,j+N), X(i+N,j), E], [X(i,j+N), X(i,j), E], and [X(i,j), X(i+N,j), E]. Three scales are used s=1,2 and 3 instead all possible.

The nucleus region is estimated by segmentation method [16]. Brightness normalization of nucleus area to the range <0-1> is necessary for independence on acquisition condition and condition of the smear. The binary mask is obtained after segmentation and is used for selection of TPM analysis area. Overall process is depicted in Fig.4.

The disadvantage of method is the use of square area at the high scale, that reduces analyzed area. It is not possible to use area outside the nucleus. In [10] square area is used and obtained preliminary results show the importance of only lowest scales.

Lowest scales correspond to the local texture features, that are similar for different regions of cell nuclei. Larger area of analysis allows reduction of the noise that is common in FD estimation, and is well observed in Richardson’s plot, typically.

The image must be registered with high optical magnification of 400x (objective 40x) and using high resolution camera (AxioCamMRc5 camera with resolution of 2584x1936 was used). It is observed for this condition that scales s = 1, 2, 3 are sufficient for the texture description due to atypia analysis.

The largest area is 9x9 pixels block that cover much better cell nuclei, what is desired for FD estimation (Fig. 5).

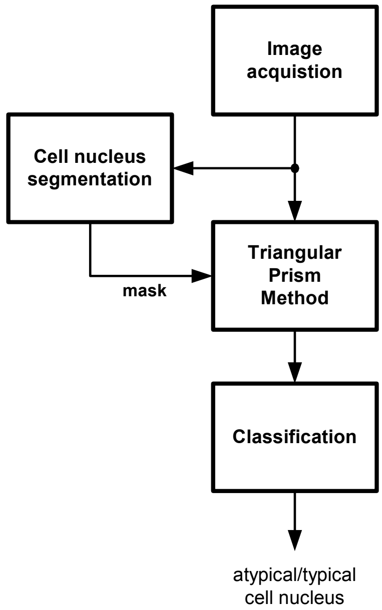

Fig.4. Schematic of image processing and classification

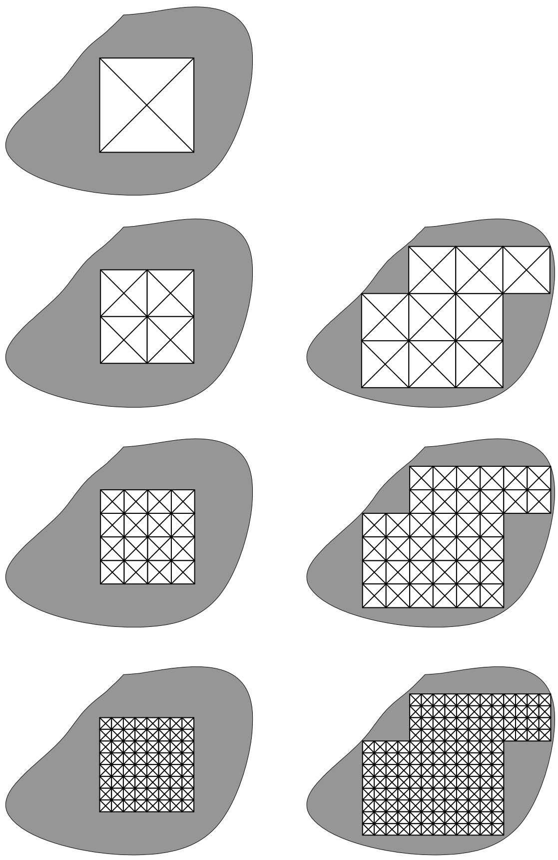

Fig.5. TPM block (top view) for example cell nucleus. Conventional technique: scales 4,3,2,1 – left column. Proposed technique: scales 3,2,1 – right column.

FD estimation is possible using Richardson's plot, but more straightforward solution is possible. The classifier does not need computed FD values and areas or differences between areas are sufficient. The differences between field areas of prism (P) for different scales are important: dP(1-2), dP(2-3). The following pair scale is applied.

$$dP(1\text{-}2) = P(1)-P(2)$$

(2)

$$dP(2\text{-}3) = P(2)-P(3)$$

The number of blocks depends on the area of cell nuclei. Normalization of the area is not necessary and, moreover, not recommended. The size of the cell nuclei is important factor considered by the cytoscreener and should be used in classification, also.

The result of proposed technique, based on the TPM for image database, is shown in Fig. 6. Two classes are well visible and they have good linear separation. Two populations of atypical cell nuclei are observed. First one has larger size and second one has similar size to the normal cell sizes.

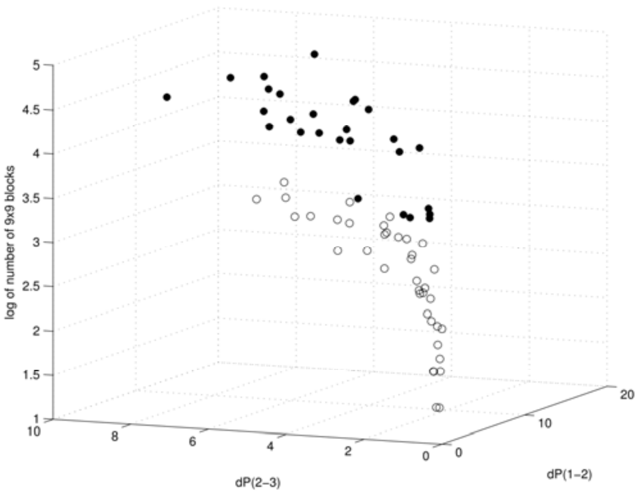

Fig.6. Separation of classes: normal cells (empty circles) – 40 cases, atypical (filled circles) – 27 cases.

Conclusions

Proposed Tiled Triangular Prism Method using segmentation of the non-rectangular area on a set of non-overlaping square blocks allows calculation of the fractal dimension with higher accuracy.

The proposed technique is well suited for the cell nuclei analysis and preclassification (final classification is provided by cytoscreener and pathomorphologist). Selection of the proper local fractal dimensions is very important for the simplification of the classifier and good separation. Advantages of the fractal dimension for the Papanicolaou smears analysis are shown and the linear separation between normal and atypical cell nuclei is obtained (Fig.6). Previous work [11] related to the application of the fractal dimensions, does not give sufficient separation, and nonlinear classification was necessary for our database.

Fractal based estimation for independent local areas are possible but not necessary for this application. The FD may vary depending on the region of the object. Application of the proposed technique does not consider such cases. The obtained values are mean values for every scale calculated for all regions.

This method would be applied for other non-rectangular objects, also.

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