Neutrosophic graph cut-based segmentation scheme for efficient cervical cancer detection

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A B S T R A C T

Cervical cancer is the most serious category of cancer that has very low survival rate in the women's community around the globe. This survival probability of women society affected by this cervical cancer can be potentially enhanced if it is detected at an early stage as they do not provide any realizable degree of symptoms in the early phase. This cervical cancer needs to be detected at an early stage through periodical checkups. Hence, the objective of the proposed work focuses on the merits of Neutrosophic Graph Cut-based Segmentation (NGCS) facilitated over the pre-processed cervical images. This NGCS-based segmentation is mainly employed for investigating the overlapping contexts of cervical smear pre-processed images for better classification accuracy. This NGCS-based segmentation is responsible for partitioning the input preprocessed image into a diversified number of non-overlapping regions that aids in better perception at the convenience. In NGCS-based segmentation, the preprocessed input image is transformed into a Neutrosophic set and indeterminacy filter depending on the estimated indeterminacy value that integrates the intensity and spatial information the pre-processed image. The utilized indeterminacy filter plays the anchor role in minimizing the indeterminacy value associated with each intensity and spatial information. Then a graph is defined over the image with unique weights are assigned to each of the image pixels based on the estimated indeterminacy value. Finally, the maximum flow graph approach is applied over the graph for determining optimal segmentation results. The results of this NGCS-based cervical cancer detection technique is proved to be excellent on an average by 13% compared to the traditional graph cut oriented cancer detection approaches.

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1. Introduction

Cervical Cancer is the abnormal development of cells in the cervical part of the woman's body. This cervical cancer is considered as the second most common kind of cancer next to the breast cancer (Garcia-Gonzalez et al., 2016). But, it is determined to be more dangerous than the breast cancer as it probably does not exhibit any kind of realizable symptoms until it reaches the serious stage of the disease (Kurniawan, 2013). The life span of the cervical can-

cer patient depends on the early stage of its detection and hence the cervical cancer needs to be diagnosed at the early stage through regular checkups (Balakrishnan et al., 2013). The most potential diagnosing tests that are more specific to cervical cancer are pap smear test, colposcopy, pelvic analysis, Human Papillomavirus examination (Riana et al., 2017). Pap Smears-based screening test is determined to be significant among the existing cervical cancer diagnosing tests present in the medical domain (Guo and Şengür, 2014). In this Pap Smears-based screening test, the speculum is inserted into the vaginal part of the women for a wide opening the vagina and cervix in order to gather cells for examination. The Pap smear cells are collected from the cervical part using a spatula and then they are placed on the glass slide for facilitating cytoplasmic investigation in the laboratory. Then, the method of Papanicolaou stain is applied over the cell components for effective classification of the collected smear cells into normal and cancer cells at an early stage of cervical cancer (Cheng et al., 2011). The challenging problem that arises during

the process of precise diagnosis of Pap smear cell-based cervical cancer detection is poor contrast and inconsistent staining of cells which make the extracting process over the cervical cells most difficult (Salah et al., 2011). In spite of large number of existing commercial methods for diagnosing the cervical cancer abnormalities, they are considered more expensive and necessitate human skill for operating (Lakshmi and Ravi, 2017). Moreover, the sample smear used for investigation consists of cell counts ranging from thousands to ten thousands which make the process of manual investigation a much more complex task.

Further, the majority of the proposed schemes existing in the literature for improving the classification accuracy during the process of cervical cancer detection rely on reliable segmentation technique. Furthermore, Graph cut-based segmentation of the preprocessed cervical cancer cells proves to be predominant in facilitating superior accuracy rate in classification (Zhao et al., 2016). Some of the most popular graph cut-based segmentation techniques include min and maximum cut, normalized graph cut and Grab cut. These existing graph cut-based segmentation techniques possesses some limitations in detecting abnormalities in the nuclei and cytoplasm of the cervical cells since they are not capable of handling the poor quality, unstable staining and poor contrasting features of the cell images to a major degree (Boykov and Funka-Lea, 2006). Thus, an effective and efficient Graph-cut based segmentation scheme is essential for achieving a maximum classification rate in detecting cervical cancer cells.

In this paper, an improved Graph-cut based segmentation scheme is presented using the merits of Neutrosophic Graph Cut by extracting nuclei and cytoplasmic boundaries of the Pap smear cells for cervical cancer detection. This Neutrosophic Graph Cut based segmentation scheme is used for achieving a better classification rate in cervical cancer detection by incorporating indeterminacy filter that plays an anchor role in reducing the indeterminacy value of the extracted intensity and spatial information of the preprocessed cancer cell images. This proposed NGCS scheme uses maximum flow algorithm for improving the rate of segmentation of the defined Neutrosophic graph. This proposed Neutrosophic Graph Cut based segmentation technique is effective in cervical cancer detection since, (a) it incorporates a two dimensional dynamic programming approach for segmenting elliptical shaped objects (pap smear cells), (b) it ensures enhanced cytoplasm and nuclei segmentation process for yielding global optimization solution and (c) it integrates constraints related to forecasted nucleus boundary, nucleus regional features, nucleus contextual priority constraint, nucleus shape information in a global way for improving the reliability in the segmentation process of the abnormal nuclei considered for examination.

In addition, the major contributions of the Neutrosophic Graph Cut based segmentation technique proposed for detecting cervical cancer are:

(a) It is rapid and reliable in resolving issues that arise due to the poor quality, contrasting features and unstable staining of the collected cervical images used for analysis.
(b) It minimizes the computation overhead since it iteratively minimizes the indeterminacy value pertaining to the spatial and intensity information about the cervical images used for examination.
(c) The rate of classification accuracy, specificity and sensitivity of the proposed scheme is proved to be more remarkable than the benchmarked graph cut-based cervical cancer detection approaches used for investigation.
(d) The Gaussian function-based kernel used in the proposed scheme is proving to confirm a superior of rate in discriminating normal from cancerous nuclei and cytoplasmic structures of the cells extracted for analysis.

The subsequent sections of the paper are structured as follows. Section 2 describes the merits and limitations of the most predominant Graph Cut-based segmentation approaches existing in the literature for the effective detection process. Section 3 presents the detailed step by step process involved in the implementation of the proposed Neutrosophic Graph Cut based segmentation technique. The results and discussions that portray the significance of the proposed Neutrosophic Graph Cut based segmentation technique in terms of accuracy; specificity and sensitivity are depicted in Section 4. Section 5 summarizes the conclusions and future plan of the proposed technique.

2. Related work

In this section, the most potential Graph Cut-based segmentation scheme that is proposed for detecting cervical cancer in the recent years is discussed.

Initially, an enhanced Grab Cut scheme that refines and adjusts the background and foreground information of pixels was proposed for facilitating efficient cervical cancer cell detection (Rother et al., 2004). This Grab Cut Approach uses the method of border matting schema for strengthening the boundaries of the cytoplasm and nuclei during the process of detection. The Grab Cut scheme was proved to improve the detection accuracy to a predominant degree as it is vital in extracting significant features of the preprocessed image with ease and simplicity in all multi-dimensional aspects related to the spatial information of the cervical cell images. Then, a dual stage graph cut segmentation scheme for effective cervical cancer cell detection was proposed based on the minimum geodesic distance (Daněk et al., 2009). In this dual stage approach, the pixels of cervical cells with maximum probability of background and foreground intensity values are determined in the first step. In the second step, the overlapping cells are potentially separated using the computation of the minimum geodesic distance that combines priori knowledge and gradient information for effective classification. Thus the quality of the preprocessed cervical images is improved for achieving better sensitivity and specificity under the process of detection.

Further, an enhanced segmentation technique that integrates two kinds of Graph Cut namely Binary Graph Cuts and Alpha expansion-based Graph Cut was proposed by Al-Kofahi et al. (2010) for effective cervical cancer cell detection. This scheme initially extracted the foreground images of Pap smear cell using Binary Graph Cut and then the significant seed point's terms as nuclei points were imposed for detecting by integrating multi-scale filtering process of Gaussian and Laplace in order to improve the rate of classification accuracy. This method of graph cuts segmentation yields better specificity and the sensitivity rate compared to the baseline max and min cut techniques of the literature. But, the classification accuracy of this approach is proving to be reduced due its limitations of its failure in resolving the unstable staining of cervical cell images. Similarly, an integrated Global and Local Graph cut scheme was proposed for segmenting the cervical cell images in order to facilitate better classification among the clustered abnormal and healthy nuclei of the cervix Pap smear cells (Zhang et al., 2014). This method of Graph cuts used an enhanced multi-way Graph Cut approach that appropriately segments nuclei and cytoplasm in the global dimension so as to resolve the data inconsistency that portrays a non-modal distribution of pixel based intensity information. This segmentation scheme is confirmed to identify the abnormalities of the cervical Pap smear cells, even when the quality and staining of the cervical cell images are poor. This scheme was also capable of combining boundary, texture, intensity and region oriented information for improving classification. This segmentation scheme was determined to suffer from the

drawback of inconsistent staining of cells as it was not effective in extracting potential information from the cervical cells.

Furthermore, Local Adaptive Graph Cut Technique (LAGCT) was proposed using two modified variants of Poisson distribution for modeling nucleus and cytoplasm background (Zhang et al., 2016). LAGCT was proposed to refine the degree of segmentation in order to achieve better classification between normal and abnormal cancer nuclei. This LAGCT scheme uses the deep learning process embedded with super pixel-based Graph cut scheme for enhancing the segmentation process over the extracted nuclei during investigation. The sensitivity and specificity of the LAGCT scheme were confirmed to be superior since it investigates the nucleus and cytoplasm structure based on multi-dimensional constraints that aids in effective detection of cancerous cells. This LAGCT approach is found to be failing in resolving the complexities related to the stain and image quality that is involved in the process of appropriate detection of pap smear cells. Then a contour-based graph cut mechanism was proposed for detecting abnormal cytoplasm and nuclei for confirming the presence of cancerous cells in the cervix (Pai et al., 2012). This contour-based cervical cancer cell detection scheme utilized a flexible decision threshold for automated detection in order to separate the cancerous cell from the extracted Pap smear cell images. This contour approach incorporated gray level gradient deviation approach for extracting the nucleus from the extracted cell used for examination. But, this contour-based approach fails to extract exact cytoplasmic and nuclei boundaries and hence the accuracy of the approach seemed to be minimized in most of the contexts.

In addition, another deep learning based cervical cancerous nucleus detection scheme was proposed for collecting spatial and intensity for training the neural network using the method of convolution for attaining better precision (Stanley et al., 2018). This deep learning based cervical cancer detection also used an iterative and linear clustering approach in order to ensure better sensitivity and specificity even when the quality of cervical images is poor and unstably stained. But, the rate of precision in classification is seemed to be comparatively lower than the LAGCT approach and binary graph cut techniques. Then, the Laplace-based Gaussian Filter-based Customized Approach (LGFCA) for segmenting and filtering the nuclei of extracting Pap smear was proposed (Agarwal et al., 2015). This LGFCA scheme utilized a second order degree of edge detector for preprocessing and feature extraction process of the cervical cancerous cells used for analysis. This LGFCA approach was also proved to be potent in resolving issues that arise due to the factors of overlapping, folded and stained cervix cells. This LGFCA technique was confirmed to detect cervical cancer cells even when they have a large number of grade lesions in the cancerous cervical cells. But, the rate of reducing the indeterminacy filtering value is comparatively lower compared to the LAGCT and min-max graph cut techniques used for cervical cancer detection.

Finally, an integrated graph and complete convolution network based cervical nuclei segmentation approach was proposed for training and learning high degree characteristics of abnormal cervical nuclei (Zhang et al., 2017). This high level of training in this integrated approach is mainly used for generating nucleus probability transformation and nucleus lack masking process. This technique used the potential method of transformation called hyper-mask for constructing the graph of the preprocessing images in order to speed up the rate of detection and classification accuracy. This mask-based segmentation approach is capable of determining the global optimal path from the estimated graph through the method of dynamic programming. This masking-based detection process is not suitable in all contexts since they lack the capability of extracting significant features from unstably stained cervical cell images due to the incorporated binary method of feature collection. Then, an Adaptive Distance Penalty Constraint-imposed

Graph Cut (ADPC-GC) mechanism for detecting cervical cancer cell was proposed based on semi-automated segmentation approach that extracts potential Region of Interest (Oyebode and Tapamo, 2016). This ADPC-GC technique uses the method of selective segmentation that enables the feasibility of assessing and monitoring the cell activity with the specific region of interest in a more precise manner. ADPC-GC technique used the merits of optimal segmentation by combining the function of the selective segmentation with graph cut energy fitness function that make it superior than the compared graph cut schemes existing in the literature.

The forthcoming section of the paper presents the detailed view on the Neutrosophic Graph Cut-based Segmentation (NGCS) Technique proposed for facilitating better classification accuracy during the process of detecting cervical cancer through the pap smear test.

3. Proposed work

The Neutrosophic Graph Cut-based Segmentation (NGCS) scheme consists of six potential steps that includes, (i) Nuclei and Cytoplasm region cropping of the Input Image of Cervical Pap Smear used for examination (automated method is used for cropping the region form tha pap smear image), (ii) Adaptive Anisotropic Filter based Preprocessing of Nuclei and Cytoplasm region, (iii) Initial Process of segmentation using Active Contour Segmentation, (iv) the process of Image unfolding for constructing the Neutrosophic Graph, (v) Incorporation of Indeterminacy Filter based cost function Estimation in order to estimate optimal Path using a maximum flow algorithm and (vi) Mapping of Neutrosophic Graph Cut determined optimal path onto input image using image unfolding reversal for improving the nucleus and cytoplasmic boundaries for cancerous cell detection. The architectural flow of the Neutrosophic Graph Cut-based Segmentation (NGCS) scheme proposed for improving the classification accuracy in detecting cervical cancer is presented in Fig. 1.

The core objective of this proposed NGCS-based segmentation approach is to present an efficient segmentation method that effectively extracts nuclei and cytoplasmic boundaries from the cervical cancer cell images. This objective of effective segmentation is always followed by potential preprocessing mechanisms for handling messy background and resolving irregular staining in the cell images. In this NGCS-based cervical cancer detection approach, the cervical cell images used for investigation are initially preprocessed by an adaptive anisotropic filter for noise elimination and morphological transforms are applied to improving the quality of the cervical cancer images before segmentation. The morphological transforms refers to the mathematical morphological transforms that uses the elements pertaining to the feature and structure in order to estimate the shape of the image. The main objective of mathematical morphology focuses on the operation that transforms one set of features to its optimal set of features. The main morphological features utilized in this proposed NGCS-
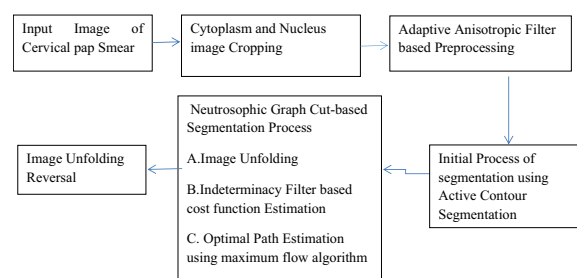

Fig. 1. Block diagram-proposed Neutrosophic Graph Cut-based Segmentation scheme.

based segmentation approach are perimeter, area, solidity, extent, eccentricity, major axis, minor axis, convex area and equivalent diameter as defined in Do Nascimento et al. (2018). In this proposed NGCS-based segmentation process, three feature selection schemes such as sparse constrained dimensionality reduction model and independent sampling *t*-test filtering model are used for feature selection. This kind of mathematical morphology transformations such as dilation and erosion aids in maintaining the correlation in some specific features of the structuring element used for mapping. Then the method of Active contour is used as the initial segmentation process followed by the method of image folding before the application of NGCS.

In NGCS, the preprocessed and initially segmented image P_{IM} represented in terms of Neutrosophic Set (NS) is expressed as $P_{M(NS)}$ with three potential values related to the foreground, indeterminate and background membership values. Thus, each pixel $P(x,y)$ in $P_{M(NS)}$ is represented as $P_{M(NS)}(x,y) = \{T_\nu(x,y), I_\nu(x,y), F_\nu(x,y)\}$. Further, the preprocessed image in NGCS is represented as the Neutrosophic Set in which each element of the NS is defined as: Let $S = \{S_1, S_2, \ldots, S_n\}$ be the set of substitute; in the considered Neutrosophic set. The substitutes S_i are $\{T_\nu(S_i), I_\nu(S_i), F_\nu(S_i)\}/S_i$, where $T_\nu(S_i), I_\nu(S_i)$ and $F_\nu(S_i)$ pertains to the true membership, indeterminate membership and false membership values respectively.

Furthermore, the true membership and indeterminate membership values are quantified using Eqs. (1) and (2) for estimating the degree of indeterminacy factor existing between the local neighborhood pixels of $P_{M(NS)}$ derived from their local spatial data and intensity value.

$$T_\nu(x,y) = \frac{I_N(x,y) - I_{N(MIN)}}{I_{N(MAX)} - I_{N(MIN)}} \tag{1}$$

and

$$I_\nu(x,y) = \frac{G_{Md}(x,y) - G_{Md(MIN)}}{G_{Md(MAX)} - G_{Md(MIN)}} \tag{2}$$

where $G_{Md}(x,y)$ and $I_N(x,y)$ refers to the gradient magnitude factor and the intensity coefficient value of each pixel on the $P_{M(NS)}$ image.

Then, the Neutrosophic Set membership values that estimate the degree of indeterminacy among the different classes of pixels with varying intensity values are determined using the method of global intensity distribution. The maximum indeterminacy value possibly assigned to the vertices of the Neutrosophic graph is 1 and the size of neighborhood considered for investigation depends on the number of vertices that has direct connection to the vertex whose values of indeterminacy is to be estimated. Further, $G_{Md}(x,y)$ used in Eqs. (1), (2) is only for the neighborhood pixels rather than the entire image.

In this proposed NGCS scheme, the method of Neutrosophic C-Means Clustering Technique (NCMCT) is used in segmentation for estimating the indeterminacy value among different classes of intensity pixels since they have been proven to resolve the limitations of indeterminacy points in most of the recent work proposed in the literature using Graph cut sets. Hence, the indeterminacy $I_{V(i)}$ and truth membership value $T_{V(i)}$ for the proposed NGCS-based segmentation approach is derived using Eqs. (3) and (4) respectively.

$$T_{V(ij)} = \frac{G}{\delta_1}(x_i - c_{p(i)})^{\frac{-2}{k-1}} \tag{3}$$

$$I_{V(ij)} = \frac{G}{\delta_2}(x_i - \eta_{MAX})^{\frac{-2}{k-1}} \tag{4}$$

where the adaptive constant 'G' of indeterminacy and truth membership value is derived using Eq. (5) based on the cluster centers

$c_{p(i)}$ and η_{MAX} that relates to the first maximum and second maximum value of $T_{V(i)}$.

$$G = \left[\frac{1}{\delta_1}\sum_{j=1}^{NC}\left(x_i - c_{p(i)}\right)^{\frac{-2}{k-1}} + \frac{1}{\delta_2}\left(x_i - \eta_{MAX}\right)^{\frac{-2}{k-1}} + \frac{1}{\delta_3}\eta^{\frac{-2}{k-1}}\right] \tag{5}$$

The aforementioned values of cluster centers $c_{p(i)}$ and η_{MAX} are modified before each iteration unless the termination constraint $\left|T_{\nu(i)}^{n=1} - T_{\nu(i)}^n\right| < \beta$ is met.

Further, a phenomenal and potential indeterminacy filter is incorporated for eliminating the impact of indeterminacy information during the process of segmentation. This prevention of indeterminacy information influence during segmentation is facilitated in this proposed NGCS scheme by utilizing a Gaussian Distribution based Kernel function as defined in Eq. (6)

$$G_{K(a,b)} = \frac{1}{2\pi\lambda_i^2}\exp(-\frac{a^2 + b^2}{2\lambda_i^2}) \tag{6}$$

where λ_i represented in Eq. (7) denotes the standard deviation value defined as the function of $P(x,y)$ depending on the relationship to the degree of indeterminacy. In addition, a and b refers to the end vertices of each edge considered in determining the indeterminacy value from the derived Neutrosophic Graph cut set.

$$\lambda_{i(x,y)} = f(P(x,y)) = sP(x,y) + t \tag{7}$$

In this context, it is clear that if λ_i is maximum when the degree of indeterminacy is maximized, then the process of filtering can derive better and smoother operation on the current neighborhood. In contrast, if λ_i is minimum when the degree of indeterminacy is minimized and thus the process of filtering can derive only least degree of smoothing operation over the current neighborhood. Thus Gaussian distribution function based Kernel function is used in the proposed NGCS scheme for mapping the degree of indeterminacy to perform better filter and smoothing operation over the neighborhood. Furthermore, the incorporated potential indeterminacy filter becomes homogenous since it is applied over the truth membership value $T_{V(i)}$ for estimating the value of indeterminacy filtering output $T_{V(i)}^1$ based on Eq. (8)

$$T_{V(i)}^1(x,y) = T_V(x,y) \oplus G_{LEAST}(a,b)$$
$$= \sum_{b=y-\frac{k}{2}}^{y+\frac{k}{2}}\sum_{a=x-\frac{k}{2}}^{x+\frac{k}{2}}T_V(x-a,y-b)G_{LEAST}(a,b) \tag{8}$$

Then the Gaussian distribution based Kernel function defined in Eq. (6) for quantifying $T_{V(i)}(x,y)$ is modified into Eq. (9) for determining the filtering output value of $T_{V(i)}^1(x,y)$

$$G_{LEAST}(a,b) = \frac{1}{2\pi\lambda_{LEAST}^2}\exp(-\frac{a^2 + b^2}{2\lambda_{LEAST}^2}) \tag{9}$$

And

$$\lambda_{LEASTi(x,y)} = f(I_V(x,y)) = sI_V(x,y) + t \tag{10}$$

where s and t refers to the linear function variables that is used for transforming the indeterminacy degree to the value of the parameter.

Furthermore, when the same indeterminacy filter is applied over the Neutrosophic C-Means Clustering Technique enforced image, the filtering output value is determined based on $T_{V(i)-NCM}(x,y)$ by utilizing the local spatial information for estimating the Neutrosophic image. Thus the value of $T_{V(i)-NCM}(x,y)$ is determined using Eq. (11)

$$T^1_{V(i)-NCM}(x,y) = T_{V-NCM}(x,y) \oplus G_{NCM}(a,b)$$

$$= \sum_{b=y-\frac{k}{2}}^{y+\frac{k}{2}} \sum_{a=x-\frac{k}{2}}^{x+\frac{k}{2}} T_{V-NCM}(x-a,y-b)G_{NCM}(a,b) \quad (11)$$

Under modified Gaussian distribution based Kernel function and standard deviation value of the NCMCT-based image as defined in Eq. (12)

$$G_{K-NCM(a,b)} = \frac{1}{2\pi\lambda^2_{NCM}} \exp(-\frac{a^2+b^2}{2\lambda^2_{NCM}}) \quad (12)$$

and

$$\lambda_{NCM(x,y)} = f(P_{NCM}(x,y)) = sP_{NCM}(x,y) + t \quad (13)$$

where k is the size of the filter kernel used for segmentation.

This estimated value of $T_{V(i)-NCM}(x,y)$ is used for constructing the graph and then the maximum flow approach are imposed over the constructed graph for improving the efficacy in cervical pap smear image segmentation in order to improve the classification accuracy of cervical cancer detection. Now, a Neutrosophic Cut $NC = (P,F)$ is defined for partitioning the graph $G = (V,E)$, which is generated based on the estimation of $T_{V(i)-NCM}(x,y)$ value. In two subsets P and F respectively. Thus the cut set of the Neutrosophic Cut $NC = (P,F)$ is the set $\{(u,v) \in E\}$ with $u \in P$ and $v \in F$ which means that the edge of the graph has the starting point in P and the terminating point in F. The Neutrosophic Cut is used in the segmentation of the cervical pear pap images for two vital reasons that include: (i) it possesses the capability of effectively solving image segmentation by formulating into an energy minimization problem which maps to the minimal cut problem or the maximum flow problem of the graph and (ii) they play a globally effective role in determining the boundary of the pap smear images of the cervical cancer cells.

In addition, the energy function used in this proposed Neutrosophic Cut-based pap smear segmentation process comprises of two constructs that are related to the smooth $E_D(NCS)$ (the measurement of agreement that exists between the function $E_F(NCS)$ and the assigned region) and data value $E_S(NCS)$ (quantifies the level to which the function $E_F(NCS)$ is smooth and its possibility of being portrayed as the n-link of the constructed graph) as described in Eq. (14)

$$E_F(NCS) = E_D(NCS) + E_S(NCS) \quad (14)$$

where $E_F(NCS)$ is the transformation function that maps the pixels into multiple groups and $E_S(NCS)$ is the smooth constrict function. In spite of the number of different energy models used in the deployment of energy function in Graph based Segmentation process of cervical cancer smear cells, The Potts Energy Model is used in this Graph based Segmentation process. Thus the transformation function $E_F(NCS)$ is modified through the expression defined in Eq. (15)

$$E_F(NCS) = \sum_{g \in P} E_D(NCS_g) + \sum_{g,h \in NP} E_F(NCS_{g,h}) \quad (15)$$

where the smooth function $E_F(NCS_{g,h})$ and data function $E_D(NCS_g)$ are defined using Eqs. (16) and (17) for two consecutive pixels g and h under NC being the neighborhood of the pixel g.

$$E_F(NCS_{g,h}) = a\phi(f_g \neq f_h) \quad (16)$$

$$E_D(NCS_g) = \left| T^1_{V(i)-NCM(g)} - C_{p(i)} \right| \quad (17)$$

with

$$\phi(f_g \neq f_h) = 1 \quad \text{if} \quad f_g \neq f_h \quad (18)$$

and

$$\phi(f_g \neq f_h) = 0 \quad \text{if} \quad f_g = f_h \quad (19)$$

where 'a' is the number constant that ranges between the value of 0 and 1. This number constant is used as the penalty value that quantifies the degree of discrimination that exists between the pixels g and h. f_g and f_h is piecewise smooth function that represents the degree n-link that exists between the neighboring pixels in a Neutrosophic graph.

Pseudocode *(I,NG,IF,Nu,Cy)*
I-Input Image
NG-Neutrosophic graph cut
IF-Indeterminacy Filter
Nu-Nucleus
Cy-Cytoplasm
MF-Maximum flow algorithm
Read the input Image I
Automated cropping of I with respect to Nu and Cy
Pre-process I with adaptive antistrophic filter
Initial segmentation using active contour segmentation
Use unfolding method on I
Calculate the cost function based on IF
Select the optimal path using MF algorithm
Use image unfolding reversal
Output: Segmented Nucleus and cytoplasm regions

Finally, the maximum flow scheme of graph cuts is used for facilitating the process of segmentation of the cervical Pap smear images from the background. Then the method of image unfolding reversal is performed for mapping the Neutrosophic Graph Cut determined optimal path onto the input image for enhancing the nucleus and cytoplasmic boundaries for cervical cancer cell detection.

4. Experimental results and discussions

The experimental investigation of the proposed NGCS–based cervical cancer cell detection process is facilitated using the Herlev dataset (Marinakis et al., 2009a,b; Chankong et al., 2014). This Herlev dataset comprises of nearly 917 cervical cell images that are collected in the university hospital of Herlev using a digital camera and the microscope. The Herlev dataset comprises of seven categories of cervical cells that includes superficial squamous, columnar epithelium, carcinoma, moderate dysplasia, mild dysplasia, severe dysplasia and intermediate squamous. Among the 917 cervical cell images of Herlev dataset 150, 192, 146 and 182 are related to carcinoma, severe dysplasia, moderate dysplasia and mild dysplasia cervical images. This proposed NGCS–based cervical cancer cell detection scheme is implemented using Matlab 2013 with the aforementioned Herlev cervical cell dataset for examination.

Initially, Fig. 2 portrays the results of the successive steps involved in the proposed Neutrosophic Graph Cut based segmentation method without Gaussian Functional Kernel. This result proved the merits of the proposed Neutrosophic Graph Cut based segmentation scheme in terms of nuclei and cytoplasmic segmentation that embeds the spatial and intensity information of pixels during graph construction. This result proves that the determination of cytoplasm and nuclei boundaries are not well defined without the incorporation of the Gaussian Function Kernel in the indeterminacy filter process of the proposed Neutrosophic Graph Cut based segmentation Scheme.

Similarly, Fig. 3 portrays the results of the successive steps involved in the proposed Neutrosophic Graph Cut based segmentation method with the Gaussian Function Kernel. This result proved
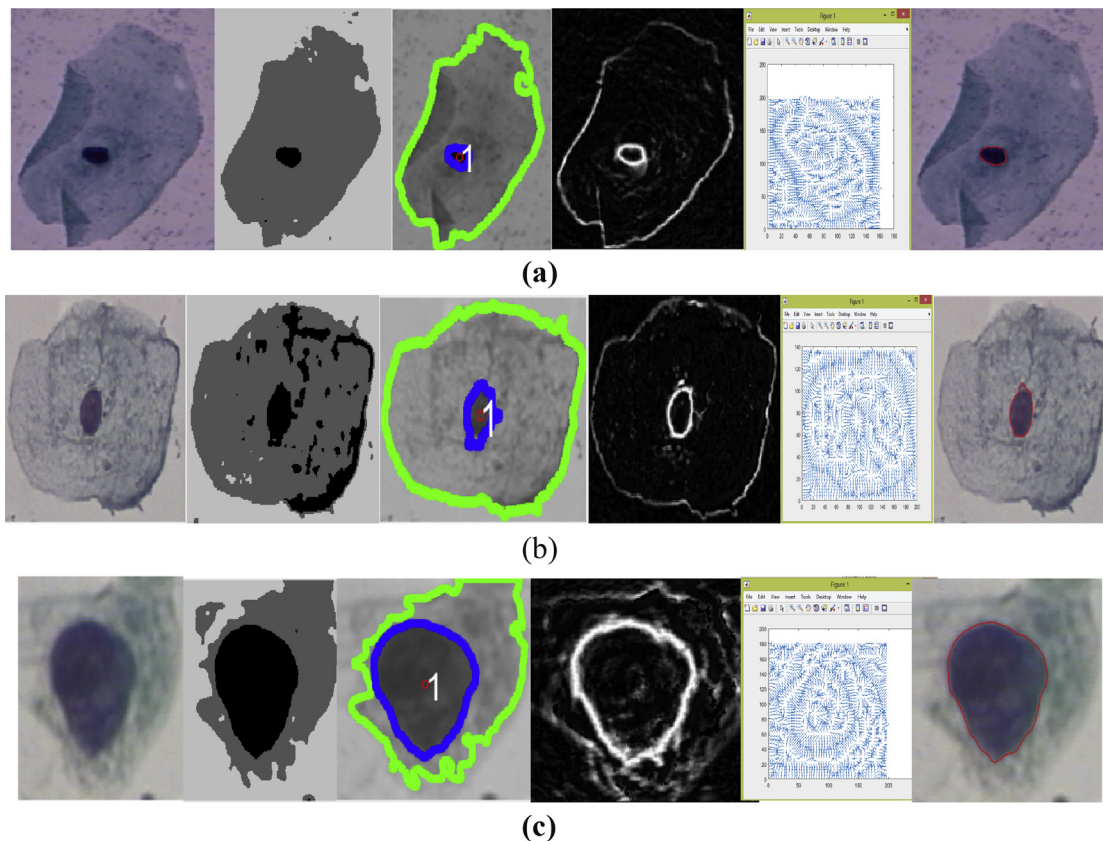
Fig. 2. Steps of the proposed Neutrosophic Graph Cut based segmentation without Gaussian Functional Kernel (the sub figure presented from left to right represents the original cervical cell image where (a) represents Superficial squamous, (b) represents Intermediate Squamous and (c) represents the Mild Dysplasia respectively which represents the category in Herlev database, the output of anisotropic diffusion filter is used for image preprocessing, then the image is segmented using Initial active contour segmentation, Neutrosophic graph cut based is used where blue labels represents the nucleus regions and green labels represent the cytoplasm region, the indeterminacy filter without the kernel filter is used to segment nucleus and cytoplasm regions, Kernel transformation map is generated where the center inner boundary represents the nucleus and the outer boundary represents the cytoplasm, Final segmented image where the red labels the cytoplasm boundary and the darker intensity pixels represent the nucleus area).

that the rate of nuclei and cytoplasmic boundary detection by integrating the spatial and intensity information of pixels during graph construction is optimal. This result proves that the determination of cytoplasm and nuclei boundaries is well defined with the utilization of the Gaussian Function Kernel in the indeterminacy filter. The results confirm that the use of the maximum flow algorithm is well suitable for resolving the issues that arise during the process of segmenting abnormal cervical nuclei and cytoplasm.

Further, Figs. 4 and 5 presents the performance of the proposed Neutrosophic Graph Cut based cervical cancer detection scheme over the existing benchmarked Graph Cut techniques like ADPC-GC, LGFCA and LAGCT based on classification accuracy and sensitivity. The classification accuracy and sensitivity of the proposed NGCS technique are 99.42% and 98.52% respectively. The accuracy rate of NGCS technique seems to be improved on an average by 3.12% superior to the ADPC-GC, LGFCA and LAGCT approaches used for comparison. This improvement rate of the proposed NGCS technique is mainly due to the Indeterminacy filter utilization that embeds Gaussian function-based kernel for efficiency. Further, this proposed NGCS scheme is determined to be potent since it used the method of morphology for feature extraction, Principal Component Analysis (PCA) for feature set selection and Support Vector Machine (SVM) for classification. Similarly, the sensitivity rate of the proposed NGCS technique is also realized to be enhanced on an average by 2.96% compared to the ADPC-GC, LGFCA and LAGCT techniques. This enhancement in sensitivity rate is due to the

potential of the proposed NGCS technique that determines the cytoplasm and nuclei boundaries of the cervical cell in an appropriate manner.

Further, Figs. 6 and 7 presents the superior performance of the proposed Neutrosophic Graph Cut based cervical cancer detection scheme over the existing benchmarked Graph Cut techniques using specificity and average time consumed for processing per image. The specificity and average time consumed for processing per image of the proposed NGCS technique are 97.54% and 2.78 s respectively. The specificity of NGCS technique is confirmed to be enhanced by 2.65% superior to the ADPC-GC, LGFCA and LAGCT approaches used for comparison. This improvement in specificity of the proposed NGCS technique is mainly due to the incorporation of the Neutrosophic set benefits that aids in precise estimation of the energy cost function using the maximum flow algorithm by classifying the boundaries of the cervical cell in a predominant manner. Likewise, average time consumed for processing per image of the proposed NGCS technique is minimized by 3.42% superior to the compared ADPC-GC, LGFCA and LAGCT techniques. This reduction in the average time consumption is achieved by utilizing two levels of segmentation that improves the probability by accurate estimation of cytoplasm and nuclei boundaries of the cervical cell in detection.

Furthermore, Figs. 8 and 9 exemplars the potential performance of the proposed Neutrosophic Graph Cut based cervical cancer detection scheme using Precision and Recall value. The Precision
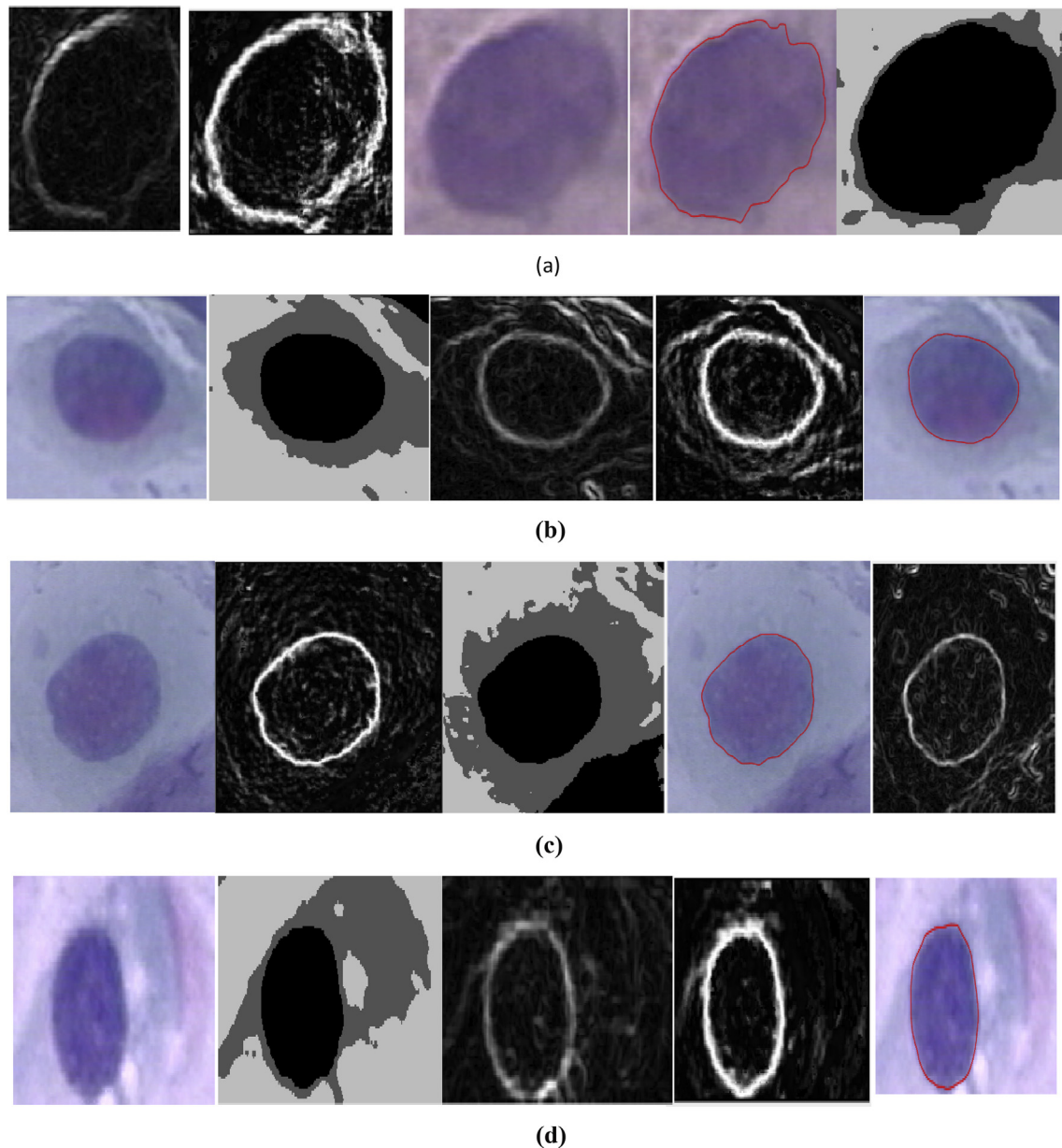
Fig. 3. Steps of the proposed Neutrosophic Graph Cut based segmentation with the Indeterminacy filter and Gaussian Functional Kernel (the sub figure presented from left to right represents the original cervical cell image where (a) represents the carcinoma, (b) represents the severe dysplasia, (c) represents Moderate Dysplasia and (d) represents columnar epithelium Anisotropic filter based preprocessing and initial active contour segmentation method, Neutrosophic Graph Cut based segmentation with red labels, where cytoplasm is represented and high intensity pixels inside represent nucleus, Maximum flow approach is applied for the detection of the nucleus and the dark high intensity pixels inside represent the nucleus region).

and Recall value of the proposed NGCS technique are 0.91±0.14 and 0.95±0.08 respectively. The Precision value of the proposed NGCS technique is determined to be improved by 5.63% superior to the ADPC-GC, LGFCA and LAGCT approaches used for comparison. In specific, the precision value of the proposed NGCS technique are 0.95±0.11, 0.91±0.12, 0.93±0.12 and 0.93±0.08 related to the carcinoma, severe dysplasia, moderate dysplasia and mild dysplasia cervical images used for investigation. Similarly, the recall value of the proposed NGCS technique is estimated to be enhanced by 4/86% superior to the ADPC-GC, LGFCA and LAGCT approaches used for comparison. In specific, the recall value of the proposed NGCS technique is 0.96±0.06, 0.93±0.10, 0.91±0.16 and 0.96±0.12 related to the carcinoma, severe dysplasia, moderate dysplasia and mild dysplasia cervical images used for investigation.

In addition, Tables 1–3 are presented for quantifying the performance of the proposed NGCS scheme over the other predominant works of the literature based on classification accuracy and sensitivity, specificity and average time consumed for processing per image, precision and recall value.

The results highlighted in Tables 1–3 infers that the classification accuracy and the sensitivity of the proposed NGCS scheme is determined to be more remarkable than the benchmarked Graph Cut based cervical cancer detection schemes used for investigation by the mean enhancement margin of 5.24% and 4.25% respectively. Similarly, the specificity and average time consumed for processing per image of the proposed NGCS scheme is determined to be improved over the other baseline approaches by a significant margin of 4.65% and 5.21% respectively. The Precision and recall value of the proposed NGCS scheme is also confirmed to be improved by
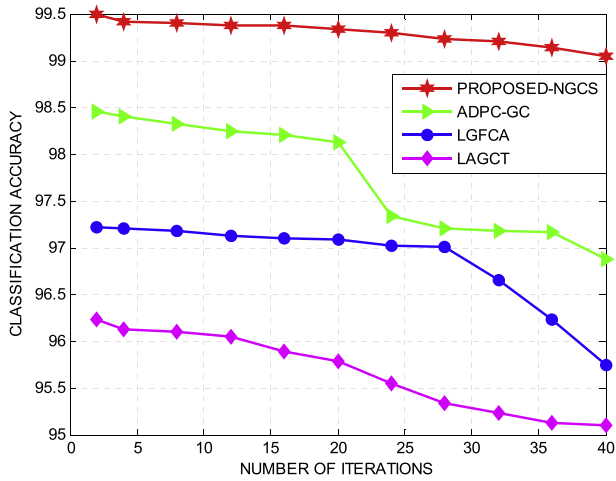
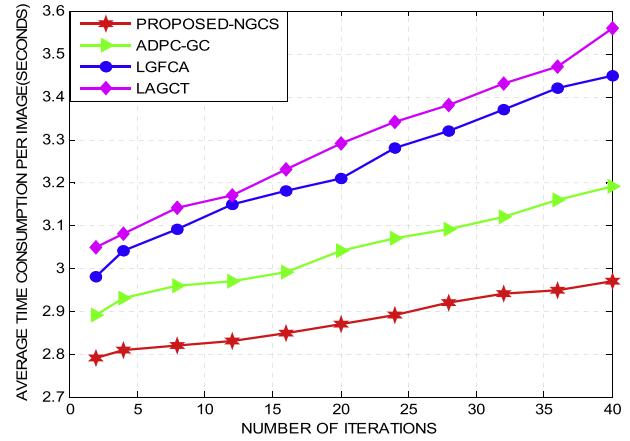**Fig. 4.** Classification Accuracy-proposed Neutrosophic Graph Cut based detection.

Fig. 7. Average time consumption for processing per image – proposed Neutrosophic Graph Cut based cervical cancer detection.
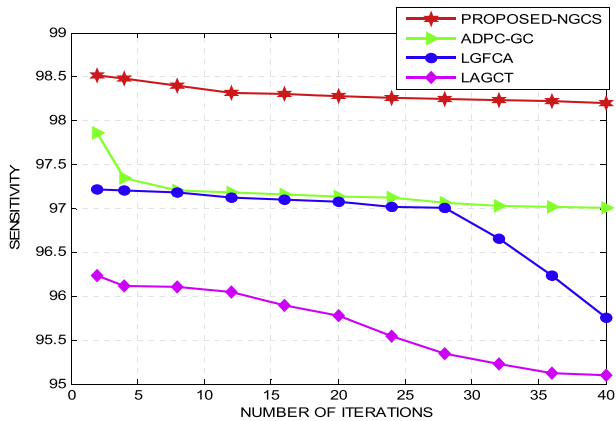

Fig. 5. Sensitivity-proposed Neutrosophic Graph Cut based cervical cancer.
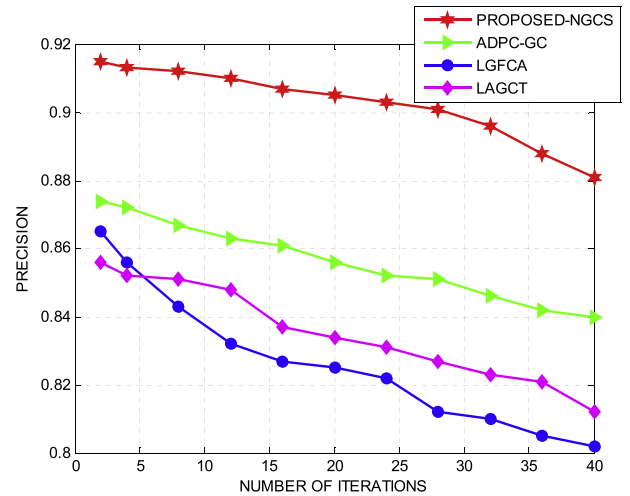

Fig. 8. Precision Value – proposed Neutrosophic Graph Cut based cancer detection.
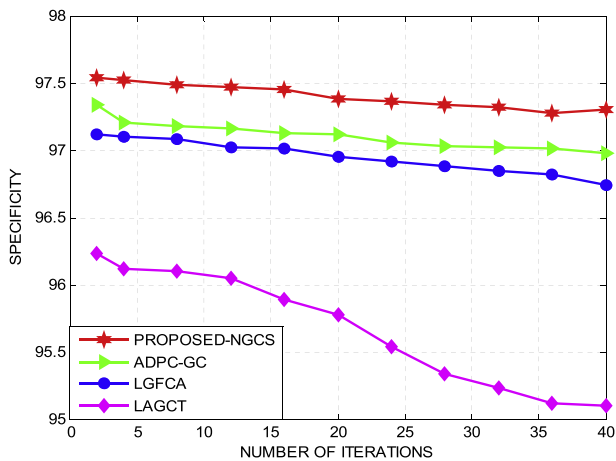

Fig. 6. Specificity-proposed Neutrosophic Graph Cut based cervical cancer detection.
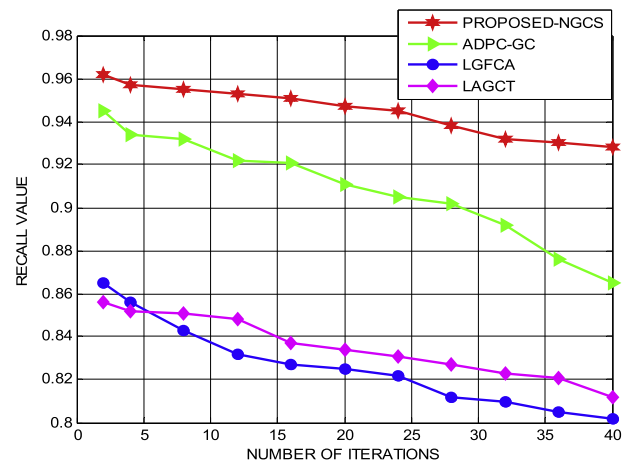

Fig. 9. Recall value – proposed Neutrosophic Graph Cut based cervical cancer detection.

4.76% and 4.34% compared to the other baseline approaches used for analysis. The result analysis of the experiments conducted on cervical image illustrates that the proposed NGCS methods produces better results than the other existing Jand manual methods which also enhances the quality of the image for the prediction and confirmation of cervical cancer. The poor staining makes the manual method complex by the amount of time consumption taken for segmentation, but the proposed method increases the accuracy and enhances the quality of the image.

Table 1
Comparative analysis of the proposed NGCS scheme based on classification accuracy and sensitivity.

First Author and Year	Classification accuracy (in %)	Sensitivity (in %)
Proposed NGCS Scheme	*99.42*	*98.52*
Rother et al. (2004)	94.52	93.42
Daněk et al. (2009)	95.23	94.52
Al-Kofahi et al. (2010)	94.56	95.23
Zhang et al. (2016)	98.21	97.43
Pai et al. (2012)	97.52	96.73
Stanley et al. (2018)	97.83	96.21
Zhang et al. (2017)	98.34	97.46

Table 2
Comparative analysis of the proposed NGCS scheme based on specificity and average time consumption for processing per image.

First Author and Year	Specificity (in %)	Average time consumption for processing per image (s)
Proposed NGCS Scheme	*99.42*	*2.29*
Rother et al. (2004)	95.12	3.56
Daněk et al. (2009)	95.16	3.68
Al-Kofahi et al. (2010)	96.56	3.86
Zhang et al. (2016)	98.12	2.86
Pai et al. (2012)	97.56	3.31
Stanley et al. (2018)	97.32	3.41
Zhang et al. (2017)	98.26	2.76

Table 3
Comparative analysis of the proposed NGCS scheme using precision and recall.

First Author and Year	Precision	Recall Value
Proposed NGCS Scheme	*0.95±0.11*	*0.96±0.06*
Rother et al. (2004)	0.90±0.08	0.93±0.12
Daněk et al. (2009)	0.90±0.14	0.92±0.14
Al-Kofahi et al. (2010)	0.91±0.12	0.94±0.08
Zhang et al. (2016)	0.94±0.16	0.94±0.13
Pai et al. (2012)	0.93±0.11	0.94±0.10
Stanley et al. (2018)	0.94±0.13	0.94±0.16
Zhang et al. (2017)	0.94±0.18	0.95±0.12

5. Conclusions

The Neutrosophic Graph Cut-based Segmentation (NGCS) scheme was presented for efficient extraction of cytoplasm and nuclei from the cervical cell images for enabling better detection of cancerous cells in the Pap smear test. The proposed NGCS scheme is identified to be predominant since it utilizes the merits of Gaussian Kernel function for reducing the spatial and intensity value of the pixels in the preprocessed image using indeterminacy filter. The significance of the proposed NGCS scheme is investigated using Herlev dataset that comprises of 917 cervical cell images related to the seven cervical cancer categories of superficial squamous, columnar epithelium, carcinoma, moderate dysplasia, mild dysplasia, severe dysplasia and intermediate squamous. The results of the proposed NBCS scheme prove to improve the classification accuracy, sensitivity, specificity, precision and recall value by 5.24%, 4.25%, and 4.65%, 5.21%, 4.76% and 4.34% compared to the reviewed research works of the literature. The results also infer that the precision and recall value of the proposed NGCS scheme is superior with the examination of the seven cervical cancer categories existing in the Herlev dataset. In the future, it is planned to formulate a hybrid Graph cut technique for cervical cancer detection by combining the operation of the proposed Neutrosophic Graph Cut and any of the traditional Graph cut schemes existing in the literature.

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Further reading

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