Original Article

Designing a Hybrid Method of Artificial Neural Network and Particle Swarm Optimization to Diagnosis Polyps from Colorectal CT Images

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Abstract

Background: Since colorectal cancer is one of the most important types of cancer in the world that often leads to death, computer-aided diagnostic (CAD) systems are a promising solution for early diagnosis of this disease with fewer side effects than conventional colonoscopy. Therefore, the aim of this research is to design a CAD system for processing colorectal Computerized Tomography (CT) images using a combination of an artificial neural network and a particle swarm optimizer. **Method:** First, the data set of the research was created from the colorectal CT images of the patients of Loghman-e Hakim Hospitals in Tehran and Al-Zahra Hospitals in Isfahan who underwent colorectal CT imaging and had conventional colonoscopy done within a maximum period of one month after that. Then the steps of model implementation, including electronic cleansing of images, segmentation, labeling of samples, extraction of features, and training and optimization of the artificial neural network (ANN) with a particle swarm optimizer, were performed. A binomial statistical test and confusion matrix calculation were used to evaluate the model. **Results:** The values of accuracy, sensitivity, and specificity of the model with a P value = 0.000 as a result of the McNemar test were 0.9354, 0.9298, and 0.9889, respectively. Also, the result of the P value of the binomial test of the ratio of diagnosis of the model and the radiologist from Loqman Hakim and Al-Zahra Hospitals was 0.044 and 0.021, respectively. **Conclusions:** The results of statistical tests and research variables show the efficiency of the CTC-CAD system created based on the hybrid of the ANN and particle swarm optimization compared to the opinion of radiologists in diagnosing colorectal polyps from CTC images.

Keywords: *Artificial intelligence, colonic polyps, computer-aided design*

Introduction

Colorectal cancer is one of the most important types of cancer in the world and the third most common cancer in Iran, and it often leads to death.[1-3] Usually, this disease is caused by cancerous colorectal polyps, and it takes at least ten years for normal colorectal polyps to become cancerous.[4,5] During this relatively long period, no clear sign of the presence of polyps in the colorectal system can be seen, and when these signs are felt or seen, the polyps have reached the advanced stages of malignancy, and their control and treatment have become very difficult and, in many cases, impossible. Therefore, early diagnosis of colorectal polyps plays a very important role in the control and treatment of colorectal cancers.[6-8]

Conventional colonoscopy is the gold standard to diagnosis lesions (including polyps) of the inner wall of the colorectal, but it also has problems.[6,9-11] This method is performed by inserting the colonoscopy probe through the patient's anus and rotating it to observe the entire internal spaces of the colorectal, and this low-invasive method increases the possibility of benign polyps becoming cancerous. Also, due to the complex structure of the colon and the movement of the probe, there is a possibility of tearing the colorectal wall. Since the head of the probe does not have the desired flexibility, some points remain out of sight during colonoscopy. Also, performing the procedure is associated with pain, which emphasizes the necessity of using painkillers.[12,13] On the other hand, bowel emptying has a significant effect on the accuracy of the diagnosis, which is done by following a special diet.[6,13]

CT Colonography (CTC) is a medical imaging method that was created with the aim of removing the limitations of the conventional colonoscopy method. And its data are used to produce a two- or

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three-dimensional representation of the colorectal. In this method, the abdominal cavity of the patient is imaged by CT after the preparation steps.[3,14-16] It should be noted that the main challenge for radiologists in interpreting CTC images is to distinguish polyps from villi and the normal structure of the colorectal mucosa. This issue leads to false-positive error.[17,18] Fixing this problem or minimizing the false positive error requires a high level of experience. To solve this challenge, computer aided diagnostic (CAD) systems have been created and are progressing.[19-21]

Artificial neural networks (ANN), which are one of the most important classification methods in artificial intelligence, and usually, they are widely used to create CAD systems.[5,20,22,23] The efficiency of the ANN depends on the settings and weights of the edges between the neurons of the network.

The particle swarm optimization (PSO) method, which is one of the global optimization methods, is derived from the collective intelligence of animals including birds and fish.[24]

Considering the importance of early diagnosis of colorectal lesions, the role of CTC-CADs as an alternative solution in the diagnosis of these lesions, and the use of artificial intelligence methods in distinguishing lesions from natural villi, the researcher sought to design a CAD system for processing colorectal CT images using a hybrid of ANN and PSO. Therefore, the aim of this research can be expressed as the development of a polyp CAD system from CTC images using evolutionary algorithms, and the most important innovation of this research is combining PSO with ANN and using it in a CTC-CAD system.

Materials and Methods

This applied study was carried out in three stages: (a) Data set preparation; (b) Model development and optimization; (c) Model evaluation. The following stages of this study are described.

Data set preparation

At first, the CTC images of patients from Loghman-e Hakim Hospital in Tehran and Al-Zahra Hospital in Isfahan who underwent imaging on the recommendation of their treating physician were collected.

The conditions for accepting the images were:

- Imaging has been done under standard protocols.
- Their CTC images are stored in DICOM format.
- At most, during one month after CTC, they have also performed a conventional colonoscopy.

This data set was formed from CTC images of 35 patients with the mentioned conditions 20 patients from Loghman-e Hakim Hospital and 15 patients from Al-Zahra Hospital. The number of 2D images obtained from the CTC of these patients was 8512.

To cleanse CTC images from the fecal material data in the colon during imaging (electronic colon cleansing [ECC]), the methods of threshold, Markov Random Field (MRF) classification, Sobel mask filtering, and Support Vector Machine (SVM) classification were used.[12,25-27] Under the supervision of the evaluation radiologist, the confusion matrix was created, and based on that, accuracy, specificity, and Area Under Curve (AUC) index were obtained. To check the performance of ECC methods, the AUC index of the implemented methods was compared, and an efficient ECC method was selected. The total number of segments of the image obtained from this step was 38253.

After that, to determine the parts of the images that contained colorectal image data (image segmentation), threshold methods, active edges, calculation of gradient value, and Sobel mask filter were used.[28-32] The images resulting from segmentation were evaluated with a radiologist, and according to his opinion, a confusion matrix was created; then accuracy, sensitivity, specificity, and AUC indexes were obtained. To check the performance of image segmentation methods, the AUC index was compared, and the method that obtained the highest value was selected as the effective image segmentation method. The parts of the image obtained from this step were 38253 parts.

Common features used in previous researches,[26,32] including active diameter, core diameter, histogram minimum, histogram maximum, histogram high value, histogram low value, standard deviation, energy, entropy, median, skewness, elongation, average, smoothness, compactness, circularity, mean shape index, shape index entropy, shape index standard deviation, and maximum of shape index, which are defined in Table 1, were calculated for all segments and placed in a matrix with dimensions of 20*38253.

Sixteen effective features were selected out of 20 features using the information gain[33] method, and other features were removed from the matrix. As a result, the dimensions of the data set matrix were reduced to 16 x 38253. With the opinion of radiologists, each row of the matrix, which represented 16 features per segment, was labeled. The label of each piece took one of the values of having polyps or not having polyps, and the distribution of rows according to their labels became uniform. Finally, the data set based on the HoldOut method, with a ratio of 70 to 30, was divided into two sets, training and testing.

Model development and optimization

The most important part in designing an ANN is determining the number of hidden layers and the number of neurons in each hidden layer. To detect the effective number of neurons in the hidden layer, several ANNs were created based on the different number of neurons in the hidden layer, and training and testing steps were executed

Table 1: Definition of image segments features

Feature	Definition
Smoothness	Reduces and suppresses image noises, and neighborhood averaging can generally be used to achieve the purpose of smoothing.
Energy	Energy is specifically important for applications such as image compression. The reason for this lies in the fact that areas with a lot of energy contain a lot of information. The term energy describes the local change of a certain quality of the image.
Circularity	A measure of circularity that excludes local irregularities can be obtained as the ratio of the area of an object to the area of a circle with the same convex perimeter.
Compactness	Compactness is defined as the ratio of the area of an object to the area of a circle with the same perimeter.
Skewness	A measure of (lack of) symmetry. For instance, if the skewness is negative, the histogram is negatively skewed. That means its left tail is longer or fatter than its right one. The positive skewness is the opposite.
Average	Image averaging is often employed to enhance video images that have been corrupted by random noise. The algorithm operates by computing the average or arithmetic mean of the intensity values for each pixel position in a set of captured images from the same scene or view field.
Shape Index Standard Deviation, Entropy, Mean, Maximum	Each individual figure is associated with a unique figure index (SI). It is possible that two small and large curves have the same SI, but the CV, which indicates the degree of their curvature, will be different. After calculating SI and CV for each voxel, the following features can be calculated for each region: Mean, entropy, standard deviation, and maximum for shape index
Elongation	Is the ratio between the length and width of the object's bounding box.
Entropy	Is a measure of the number of bits required to encode image data. The higher the value of entropy, the more detailed the image will be.
Active Diameter	The diameter of the circle with the same surface as the desired shape
Median	Is the middle number in a sorted, ascending or descending list of intensity value
Histogram Low and High Value, Histogram Minimum and Maximum	An image histogram is a graphical representation of the number of pixels in an image as a function of their intensity. Histograms are made up of bins; each bin shows the range of a certain intensity value, and from it, the features Histogram Low Value, Histogram High Value, Histogram Minimum, and Histogram Maximum can be obtained.
Standard Deviation	The standard deviation provides a measure of the intensity dispersion of the gray level of the image and can be understood as a measure of the power level of the alternating signal component obtained in the imaging.
Core Diameter	The core diameter of a tile is defined in such a way that the area in a tile is defined in such a way that the gradient of each voxel is less than the average gradient of the tile.

ten times for each created network and accuracy was calculated in each step. Then, the results of the accuracy of the networks with different numbers of neurons were given in the T-test for the paired samples.

The previous test (pretest) was performed by running an ANN with less number of neurons in the hidden layer, and the post-test (posttest) was performed by running an ANN with a higher number of neurons in the hidden layer. The dependent variable of the test was the accuracy values obtained from ten times of running the network. The variable values are numbers between 0 and 1 based on accuracy. The null hypothesis means that there is no significant difference between the pretest and posttest values.

After the tests, among all the networks, the network with the least number of neurons was selected. After determining the effective number of neurons in the hidden layer, to detect the effective number of hidden layers, several ANNs were created based on the different number of hidden layers, and among them, the network with higher efficiency was selected based on the AUC index.

Then, multi-objective PSO (MOPSO) was created to optimize the weight of edges and biases in ANN. The weight of the edges and the biases of the network were considered the particles (solution) in the MOPSO, and the fitness function of each particle was considered from the two objectives of increasing the sensitivity and the specificity.

The effective ANN was combined with the optimal settings of MOPSO, and the training of the hybrid model was done with the training set. The best result of the trained hybrid model was selected and evaluated with the testing set. Accuracy, sensitivity, specificity, and the AUC index were calculated, and the structure of the hybrid model was used in the implementation of the CAD system. Then, in order to check the significance of the obtained results, the model diagnoses were included in the McNemar test.

Model evaluation

Considering that conventional colonoscopy is the gold standard for diagnosing colorectal lesions, to evaluate the accuracy of CAD system results, in one step, the radiologist's diagnosis from the CTC images of the patients was compared with the gastroenterologist's opinion obtained from the conventional colonoscopy report of the same patients. Then, the same comparisons were made with the output of the CAD system, and the total and percentage of agreement of opinions in both comparisons were calculated.

To evaluate the values of sensitivity, specificity, and accuracy of the obtained optimal model, the label of all the samples and the diagnosis of the model were entered in IBM SPSS Statistics 25, and the McNemar test was performed on them. The null hypothesis means that the results of the values are not significant, and the alternative hypothesis is considered to mean that the resulting values are significant.

The binomial test was used to check the significance of the difference between these two comparisons. In this test, the null hypothesis was considered to be the absence of a significant difference between the diagnosis of CTC-CAD from CTC images and the radiologist's diagnosis from the same images. The alternative hypothesis was considered a significant difference between the same diagnoses. For the test proportion in the binomial test, the percentage of the radiologist's matching diagnosis with the colonoscopy report was set.

Results

After implementing the described methods for ECC on CTC images based on the AUC index, the following results were obtained:

- 0.0905 for the thresholding method
- 0.7293 for the Markov random classification method
- 0.6946 for the Sobel mask filter
- 0.8455 for support vector machine

After implementing the described methods for CTC image segmentation based on the AUC index, the following results were obtained:

- 0.56897 for the thresholding method
- 0.81155 for active contour
- 0.85027 for calculation of the gradient value
- 0.87477 for the Sobel mask filter

Table 2 shows the value of the information gain of the features based on the implementation of the InfoGain method on the research data set and the ranking of the features. After calculating the information gain of each feature, ANN was implemented with a dataset consisting of different numbers of superior features, and the results showed that the ANN model with a dataset consisting of 16 features was able to increase the AUC index, and since then, the value of this index has not changed significantly. Therefore, sixteen effective features were selected.

After determining the most efficient combined model, the values of sensitivity, specificity, accuracy, and AUC of the model were obtained as 0.9298, 0.9889, 0.9354, and 0.889631, respectively and the result of the McNemar test shows the correctness of the results with a P value = 0.000.

Table 2: Ranking of effective features based on the results of the InfoGain method

Feature	Information gain	Rank
Smoothness	0.3561	1
Energy	0.3117	2
Circularity	0.2432	3
Compactness	0.1085	4
Skewness	0.1028	5
Average	0.0901	6
Shape index standard deviation	0.0782	7
Elongation	0.0639	8
Entropy	0.0637	9
Active diameter	0.0566	10
Shape index entropy	0.0350	11
Median	0.0310	12
Histogram low value	0.0141	13
Standard deviation	0.0124	14
Mean shape index	0.0121	15
Histogram minimum	0.0106	16
Core diameter	0.0056	17
Maximum of shape index	0.0032	18
Histogram high value	0.0004	19
Histogram maximum	0.0001	20

The results of radiologist diagnosis and CTC-CAD diagnosis from CTC images of the Loghman-e Hakim Hospital dataset compared to the expert opinion from the colonoscopy report of the same patients in the three groups of presence of polyps, absence of polyps, and overall agreement are given in Table 3.

Among the 20 records in the research dataset of Loghman-e Hakim Hospital, the radiologist was able to diagnose 13 records correctly, and the CTC-CAD software was able to diagnose 17 records correctly. According to frequency percentage, two diagnostic methods have been able to obtain 65% and 85%, respectively.

Table 4 shows the results of the binomial test to compare the ratio of diagnosis with matching of the radiologist and CTC-CAD from the images of the Loghman-e Hakim Hospital dataset.

The diagnosis of CTC-CAD software with a significance level of 0.044 is significantly different from the diagnosis of the radiologist regarding all the matching diagnoses of the patients of Loghman-e Hakim Hospital.

The results of radiologist diagnosis and CTC-CAD diagnosis from CTC images of the Al-Zahra Hospital dataset compared to the expert opinion from the colonoscopy report of the same patients in the three groups of the presence of polyps, absence of polyps, and overall agreement are given in Table 5.

Among the 15 records in the research dataset of Al-Zahra Hospital, the radiologist was able to diagnose 10 records correctly, and the CTC-CAD software was able to diagnose

Table 3: Comparison results of radiologist and CTC-CAD diagnosis based on the data of Loghman-e Hakim Hospital

Diagnoses	Polyp present		Polyp absence		Matching	
	Radiologist	CAD	Radiologist	CAD	Radiologist	CAD
True	2 (25%)	7 (87.5%)	11 (91.7%)	10 (83.3%)	13 (65%)	17 (85%)
False	6 (75%)	1 (12.5%)	1 (8.3%)	2 (16.7%)	7 (35%)	3 (15%)
Total	8		12		20	

Table 4: The results of the binomial test from the patients of the Loghman-e Hakim Hospital

Group	Number	CAD matching diagnoses Frequency ratio	Radiologist matching diagnoses Frequency ratio	Significance level
True diagnosis	17	0.85	0.65	0.044
False diagnosis	3	0.15		
total	20	1.00		

Table 5: Comparison results of radiologist and CTC-CAD diagnosis based on the data of the the Al-Zahra Hospital

Diagnoses	Polyp Present		Polyp Absence		Matching	
	Radiologist	CAD	Radiologist	CAD	Radiologist	CAD
True	4 (57%)	7 (100%)	6 (75%)	7 (88%)	10 (67%)	14 (93%)
False	3 (43%)	0 (0%)	2 (25%)	1 (12%)	5 (33%)	1 (15%)
Total	7		8		15	

14 records correctly. According to frequency percentage, two diagnostic methods have been able to obtain 67% and 93%, respectively.

Table 6 shows the results of the binomial test to compare the ratio of diagnosis with matching of the radiologist and CTC-CAD from the images of the Al-Zahra Hospital dataset.The diagnosis of CTC-CAD software with a significance level of 0.021 is significantly different from the diagnosis of the radiologist regarding all the matching diagnoses of the patients of Al-Zahra Hospital.

Discussion

According to the findings obtained from the implementation of electronic cleansing methods, CTC images identified that the MD method, which uses the SVM classification, is more efficient than the MRF method, with a difference of nearly 0.12 in the AUC index, which ranks second. The difference between the AUC index values of the second and third rank is 0.035. The large difference between the first and second ranks compared to the second and third ranks also confirms the effectiveness of the MD method as a reference. Therefore, the MD method was used as the method for ECC in this research.

According to the findings obtained from the implementation of segmentation methods, it can be seen that the maximum difference between the first rank and the third rank of these methods based on the AUC index is 0.06, and this insignificant difference shows the effectiveness of all three methods in CTC image segmentation. However, due to the higher value of the AUC index of the Sobel mask method, this method was used for segmentation of CTC images in this research.

By comparing the findings from Table 2, it can be seen that the features for which the value of the information gain obtained by the InfoGain method is less than 0.01 have no effect on the efficiency of the model. Therefore, it was possible that without testing the efficiency of the models with a data set consisting of a different number of superior features (with higher information gain) and only by applying the threshold limit of 0.01 on the value of information gain obtained from this method, get effective features.

According to the P value = 0.000 from the McNemar test, the null hypothesis was rejected and the alternative hypothesis was accepted, which means that the results of the values of sensitivity, specificity, and accuracy are confirmed.

Based on the results given in Table 3 and after comparing the radiologist's diagnosis from the CTC images of the dataset records prepared from Loghman-e Hakim Hospital with the gastroenterologist's opinion from the colonoscopy report of the same records, the frequency percentage of the total matching diagnosis of the radiologist was 65%, the matching diagnosis for the presence of polyps was 25%, and for the absence of polyps it was 91.7%. Then, the diagnosis of the CTC-CAD software, which was created based on the combination of ANN and PSO from the CTC images of the data set records prepared from Loghman-e Hakim Hospital, was compared with the gastroenterologist's opinion based on the colonoscopy report of the same records, and the frequency percentage of the total matching diagnosis with CTC-CAD was 85%, and the diagnosis for the presence of polyps was 87.5%, and for the absence of polyps, it was 83.3%. These numbers show that the total frequency

Table 6: The results of the Binomial test from the patients of Al-Zahra Hospital

Group	Number	CAD matching diagnoses Frequency ratio	Radiologist matching diagnoses Frequency ratio	Significance level
True diagnosis	14	0.93	0.67	0.021
False diagnosis	1	0.07		
Total	15	1.00		

percentage of matching diagnoses of the CTC-CAD software was higher than that of radiologists.

To investigate the significance of these differences, a binomial test was conducted between the frequency percentages of matching diagnoses based on the results from the data set of Loghman-e Hakim Hospital. According to the *P* value = 0.044 visible in the results of the binomial test between the total frequency percentage ratio of CTC-CAD matching diagnosis and radiologist matching diagnosis [Table 4], which is smaller than 0.05, the null hypothesis is rejected and the alternative hypothesis is proved. This means that there is a significant difference in the total frequency percentage of CTC-CAD matching diagnoses compared to the frequency percentage of radiologist matching diagnoses.

Based on the results given in Table 5 and after comparing the radiologist's diagnosis from the CTC images of the dataset records prepared from Al-Zahra Hospital with the gastroenterologist's opinion from the colonoscopy report of the same records, the frequency percentage of the total matching diagnosis of the radiologist was 67%, the matching diagnosis for the presence of polyps was 57%, and for the absence of polyps it was 75%. Then, the diagnosis of the CTC-CAD software, which was created based on the combination of ANN and PSO from the CTC images of the data set records prepared from Loghman-e Hakim Hospital, was compared with the gastroenterologist's opinion based on the colonoscopy report of the same records, and the frequency percentage of the total matching diagnosis with CTC-CAD was 93%, and the diagnosis for the presence of polyps was 100%, and for the absence of polyps, it was 88%. These numbers show that the total frequency percentage of matching diagnoses of the CTC-CAD software was higher than that of radiologists.

To investigate the significance of these differences, a binomial test was conducted between the frequency percentages of matching diagnoses based on the results from the data set of the Al-Zahra Hospital. According to the *P* value = 0.021 visible in the results of the binomial test between the total frequency percentage ratio of CTC-CAD matching diagnosis and radiologist matching diagnosis [Table 6], which is smaller than 0.05, the null hypothesis is rejected and the alternative hypothesis is proved. This means that there is a significant difference in the total frequency percentage of CTC-CAD matching diagnoses compared to the frequency percentage of radiologist matching diagnoses.

Conclusions

About the performance of the algorithm, according to the evaluation results and statistical tests, it can be concluded that the proposed algorithm for polyp diagnosis based on the hybrid method of artificial neural network and PSO was able to work more efficiently compared to the opinion of radiologists diagnosis in the matching diagnosis. As a result, that shows the efficiency of CTC-CAD compared to radiologists in the interpretation of CTC images.

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Ethical Considerations

This research has been approved by the ethics committee: its code is IR.SBMU.REC.1396.164.

Authors' Contributions

H. Moghaddasi and H. Beigi participated in all part of this study.

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Conflicts of interest

There are no conflicts of interest.

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