A Study on Optimization Techniques in Feature Selection for Medical Image Analysis

Mohan Allam
Research Scholar
Department of Computer Science
Pondicherry University, Puducherry
mohanallam@gmail.com

Dr. M. Nandhini
Assistant Professor
Department of Computer Science
PondicherryUniversity, Puducherry
mnandhini2005@yahoo.com

***Abstract*—Reliable and rapid diagnosis of diseases is required to handle health problems efficiently at an early stage. The best possible way to accomplish this is developing an imaging system to evaluate the problem and suggest remedial action for treatment. The major objective of medical image analysis will be supporting medical doctors in specific clinical applications requiring the visual assessment of medical images in order to evolve the objectivity and repeatability of analysis. The medical image analysis involves different phases of acquiring medical images from various medical datacenters, extract relevant features, feature dimension reduction and classification of medical images based on the optimal features. In this review paper, we tried to sum up all the existing feature dimension reduction techniques based on optimization algorithms and proposed a new method to optimize the solution space.**

Keywords: Imaging system, Feature Selection, Optimization Algorithm, Medical Images, Genetic Algorithm, Evolutionary Algorithm, Support Vector Machine, Teaching Learning based Optimization.

I. INTRODUCTION

Automation of medical disease diagnosis is becoming very popular, particularly when a quick report is required. Currently, scientists often preference to slow and manual analysis to extract information from the images, which is time-consuming and definitely not scalable for studies on large-scale medical image databases. Medical images have been proven critical to seek answers to many important problems related to disease diagnosis and prediction and drug target confirmation. Implementation of advanced imaging systems for health is a challenging task for engineers. In standardized imaging systems, feature classification can be performed through exhaustive search of known features dataset collected from various medical research centers against the unknown features of test images. This motivates our proposal in the specialization of medical image processing.

The initial stage in the medical image analysis involves collecting a huge number of medical images related to a particular target disease. The impact of medical imaging on medicine is rapidly growing with the recent development of advanced imaging techniques like Computed Tomography (CT) for diagnosing many cancers (lung, liver, and pancreatic cancer), Ultrasound, Magnetic Resonance Imaging (MRI) to differentiate normal and diseased soft tissues of the body, Functional MRI (fMRI), Single Photon Emission Computed Tomography (SPECT), X-Ray and Positron Emission Tomography (PET) to know the functioning of tissues and organs. The medical images taken from different imaging modalities are stored in the medical database for further research by various research centers for better training the proposed system. The images usually suffer from low contrast, blur, noisy and diminished colors and need to be pre-processed for enhancing the quality by removing the noise. The literature survey reveals that different improved algorithms are used for enhancing the image quality.

Second stage involves the separation of background from the object followed by partitioning the regions of interest with image segmentation based on various features like texture, color and depth measurements. The selection of a segmentation technique is decided by the type of image and characteristics of the problem (disease) selected.

Third stage is feature identification and extraction. The accuracy of classification decreases with the increase in number of features extracted from the image. We can call it as the curse of dimensionality in the vision of classification. To deal with this problem, feature optimization is a suggestible choice.

Fourth stage is features selection which is derived from the known features using robust Optimization algorithms for better identification of disease from the medical images. [1] Proposed a classification approach for medical X-ray images. Features extraction is done based on shape and texture characteristics. Genetic Algorithm (GA) is used for selection of optimal features vector. Finally classified the images based on random forest and vector machine (SVM) classifiers. [2] Proposed a method to improve the accuracy of medical image classification. It uses GA to form the optimal feature subsets and achieved higher classification accuracy with k-nearest neighbor (k-NN), J48 and Naive Bayes (NB) algorithms.

Feature selection is described as an optimization problem and aims to decrease the computation time and improve the precision with a feature optimization algorithm by removing redundant, unrelated and noisy features. So, it is essential to develop an efficient algorithm to extract relevant good features from the medical images for classification. In the next section we are going to explain various image feature selection algorithms based on different modalities, diseases and categories of Optimization algorithms. In the final section we will explain the proposed improved optimization algorithm and its variants for feature selection.

II. LITERATURE REVIEW

Population-based algorithms which are inspired by Nature find best solutions to the difficult feature optimization problems. Evolutionary Algorithms (EA) and swarm intelligence (SI) are two important categories of optimization algorithms to extract the potential features from the sample medical images.

A. Evolutionary Algorithms based Feature Selection

Evolutionary Algorithms are used as optimization techniques which reduce the dimensionality of features. Genetic Algorithm, Genetic Programming, Evolution Strategy (ES), Evolutionary Programming, Differential Evolution are well-known evolutionary algorithms used for selecting optimal features from the extracted feature set in diagnosing the critical diseases like Brain, Breast and Lung cancer from medical images.

1) Brain Disease Diagnosis

Here we are presenting a review on various EA based Optimization of brain medical image feature sets.

Padmaet al. [3] presented a method for textural feature selection using GA, and used the SVM, Back Propagation Neural network (BPN) classifiers to classify and segment the abnormal brain tumor region with CT images. This method effectively works well for detection of abnormal tumor region with high specificity, sensitivity and accuracy.

Savas Okyay et al. [4] recommend a method, which diagnosis the brain images of dementia patients by examining the critical regions to create different feature groups such as the cortical volume, thickness, and surface area. Searching an optimal feature subset process is carried out for each feature group. At the end, a wrapper feature selection technique namely genetic algorithm is used with Naive Bayes and SVM classifiers. The accuracy results up to 93.7%.

Accamma et al. [5] proposed a method for decoding cognitive states from fMRI data. GA is used for selection of voxels which plays important role for finding the difference in the size and shape of the brain of dissimilar subjects. Feature selection using GA performed better than other popular feature selection techniques.

Shahamat et al. [6] improved a method for taxonomy of schizophrenia using GA from FMRI data. First, the FMRI scans are realigned, normalized and smoothed using SPM8 software. Then, Principal Component Analysis (PCA) is used for feature vector reduction and ICA for independent components estimation. Linear Discriminant Analysis (LDA) and GA are used for finding the histogram bins with most discrimination power. Finally, a Euclidean-based classifier is used for classification of subjects into predefined groups.

Ahmed Kharrat et al. [7] compared classical sequential methods based on number of features, reduction rate and classification correctness with genetic method. GA achieved adequate classification precision with only 5 features out of 44. The optimal feature such as homogeneity, individual mean of contrast, sum average, sum variance and range of autocorrelation provide best classification performance.

Ahmed Kharratet al. [8] gave a new scheme for automatic classification of MR brain images. The method uses Wavelets Transform (WT) for feature extraction. It employs GA for feature selection which gives less computational load to classification algorithm and achieved a reduction rate of 88.63%. Support Vector

Machine(SVM) classifier separates MR brain images into normal and abnormal with a classification rate of 100%.Common classification techniques for GA based feature selection are shown in the Table I.

TABLE I.COMMON IMAGING MODALITIES & CLASSIFICATION TECHNIQUES FOR GA BASED FEATURE SELECTION IN BRAIN DIAGNOSIS.

Reference	Imaging Modality	Classification Technique	Results
[3]	Computed Tomography	Support Vector Machine(SVM)	Classification accuracy of SVM is 96%
[4]	Magnetic Resonance Imaging	SVM and Naive Bayes Classifiers	Accuracy results up to 93.7% with different Classifiers.
[5]	Functional Magnetic Resonance Imaging	Nearest neighbor classifier	GA show good classification accuracy.
[6]	Functional Magnetic Resonance Imaging	Euclidean distance and majority vote method	Proposed method is analogous to other state-of-the-art work.
[7]	Magnetic Resonance Imaging	Support Vector Machine(SVM)	Achieved acceptable accuracy with only five out of 44 features.
[8]	Magnetic Resonance Imaging	Support Vector Machine(SVM)	Feature size is reduced by 88.63%

2) Breast Disease Diagnosis

Here we are presenting a review on various EA based optimization of breast medical image feature sets.

Sasikala et al. [9] proposed a Shapely Value Embedded Genetic Algorithm (SVEGA) selecting the gene subset from the high dimensional gene data to improve the accuracy of breast cancer diagnosis. SVEGA uses "include" and "remove" operators to recognize the GA solution. The classification accuracy rate is improved with the classifiers SVM, k-NN, NB and J48 to classify between the typical and irregular tissues.

Ravi Kumar et al. [10] worked on classification of diseases with a combination of GA and SVM techniques for feature selection and classification. Authors concluded that the proposed genetic-SVM is very powerful for different medical data sets to find a suitable feature subset in getting better results than other methods.

Shokoufeh Aalaei et al. [11] implemented a diagnosis system for breast cancer with the help of GA for selecting the best subset of features. Artificial Neural Network and GA-classifier were used to evaluate proposed feature selection method on Wisconsin Breast Cancer Datasets.

Ludvık Tesa et al. [12] addressed a problem of feature (quantifiable indexes) selection for texture analysis in ultrasound images. In this work they used GA for a feature subset selection. They used Gaussian mixture model based on Bayes classifier for automatic classification of healthy thyroid gland and thyroid gland with chronic inflammation.

Common classification techniques for breast diagnosis based on GA are shown in Table II.

TABLE II.COMMON CLASSIFICATION TECHNIQUES FOR GA BASED FEATURE SELECTION IN BREAST DIAGNOSIS

Reference	Classification Technique	Results
[9]	SVM, KNN, NB, J48	Features reduced to 6 from 24,481
[10]	Random Forest Based	Classifier achieves better results than other methods.
[11]	ANN, GA Classifier.	Feature selection improved the accuracy, sensitivity and specificity of classifiers.

3) Lung Disease Diagnosis

Shenshen Sun et al. [13] Describes a lung nodule detection algorithm which adopts the improved GA algorithm with specific parameters like mutation and crossover probabilities to select the optimal feature combination from the feature pool to establish SVM classifier.

Xiabi Liu et al. [14] Recognizes Signs of Lung Diseases in CT Images with a combination of Fisher Criterion based feature selection and Genetic Optimization.

B. Swarm Intelligence based Feature Selection

Particle Swarm Optimization (PSO), Firefly (FF), Artificial Bee Colony (ABC), Cuckoo search, Ant Colony Optimization (ACO), Shuffled Frog Leaping (SFL) are some of the popular swarm intelligence based algorithms.

Sasi Kumar et al. [15] recommend a combination of information gain and PSO for feature selection. The extracted features were trained with the existing Multilayer Perceptron Neural network (MLP-NN) classifier and compared with the proposed Fuzzy Softmax-MLP-NN. The proposed method decreases the overall processing time for a given query and achieved the classification accuracy of 98.27%.

Pooja Malviya et al. [16] developed a feature subset selection technique based on particle of swarm optimization for brain stroke detection. The proposed system achieved better compression over the previous methods such as Wavelet Transform and Integer Wavelet Transform.

Vartika Agrawalet al. [17] presented a comparative study of image classification over CT images of cervical cancer. Selection of image features was performed by Artificial Bee Colony algorithm. The classifier k-NN is showing 97%, 100% accuracy with biased and unbiased dataset respectively. SVM with linear kernel is showing 93%, 99% accuracy with biased data set and radial basis as a kernel is applied. Table III shows common selection methods using swarm intelligence.

TABLE III. COMMON MODALITIES AND FEATURE SELECTION METHODS USING SWARM INTELLIGENCE

Reference	Imaging Modality	Application	Feature selection method	Results
[15]	MRI	Medical Image Retrieval System	PSO	Decreases the processing time for a given query with accuracy of 98.27%.
[16]	CT & MRI	Brain Stroke Detection	PSO	Image fusion technique improved the image quality index values.
[17]	CT	Classification of Cervical cancer	ABC	K-NN is showing 97%, SVM with linear kernel is showing 93% accuracy.

C. Other Feature Selection Methods

Along with the above optimization algorithms we presented some other feature selection methods.

Shuihua Wang et al. [18] proposed a Pathological Brain Detection (PBD) by a Novel Image Feature - Fractional Fourier Entropy (FRFE). He used Welch's t-test (WTT) & Mahalanobis distance (MD) to select significant FRFEs for implementing a PBD system. They used multiple classifiers to obtain superior results than other techniques.

Gladis Pushpa Rathi et al. [19] addressed the problem of classification by MRI brain images. They used PCA and LDA methods for selection of Texture, Intensity and shape features in the classification of tumor as white matter, CSF, Gray matter, normal and abnormal area. SVM classifier achieved 98.87% accuracy.

Shirbani et al. [20] framed a new hybrid method of feature selection with a modified sequential search method for the classification of biomedical datasets. It includes a new filtering feature called pre-selection measure. This measure benefits from combination of the Relief algorithm and the Pearson correlation as an evaluation of a feature's predictability. The proposed wrapper method is an optimized SVM method that selects the best or the worst features based on the average AUC measure of k-fold cross validation.

Vamsidhar Enireddy et al. [21] made an investigation on the retrieval of compressed medical images. Images are compressed using the visually lossless compression technique. Shape and texture features are extracted and best features are selected using the fisher technique and minimum redundancy maximum relevance (mRMR).A list of familiar feature selection methods is given in Table IV, along with the appropriate references. Classification of various feature selection methods are shown in the figure 1.

TABLE IV. COMMON FEATURE SELECTION TECHNIQUES FOR VARIOUS DISEASES

Reference	Disease	Feature Selection Method	Results
[18]	Pathological Brain Detection	WTT & MD	Achieved an accuracy of 100%, 99.57% on datasets containing 66, 255 brain images.
[19]	Classification of Brain Tumor images	PCA and LDA	The classification accuracy by SVM is 98.87%.
[20]	Classification of Biomedical Datasets	SFFS	Explicit reduction in the relative execution time and the number of selected features.
[21]	Retrieval of Compressed Medical Images	Fisher Score and mRMR	The mRMR Feature selection performed better than Fisher Score.

Along with the evolutionary and swarm intelligence based algorithms, we have various former procedures which act based on the rule of natural phenomenon. TLBO algorithm [22] is one of them which require simply general controlling constraints resembling population size and number of generations. Considering this fact, we preferred a variant of Teaching Learning based optimization (TLBO) algorithm which does not entail algorithm-specific constraints at all.

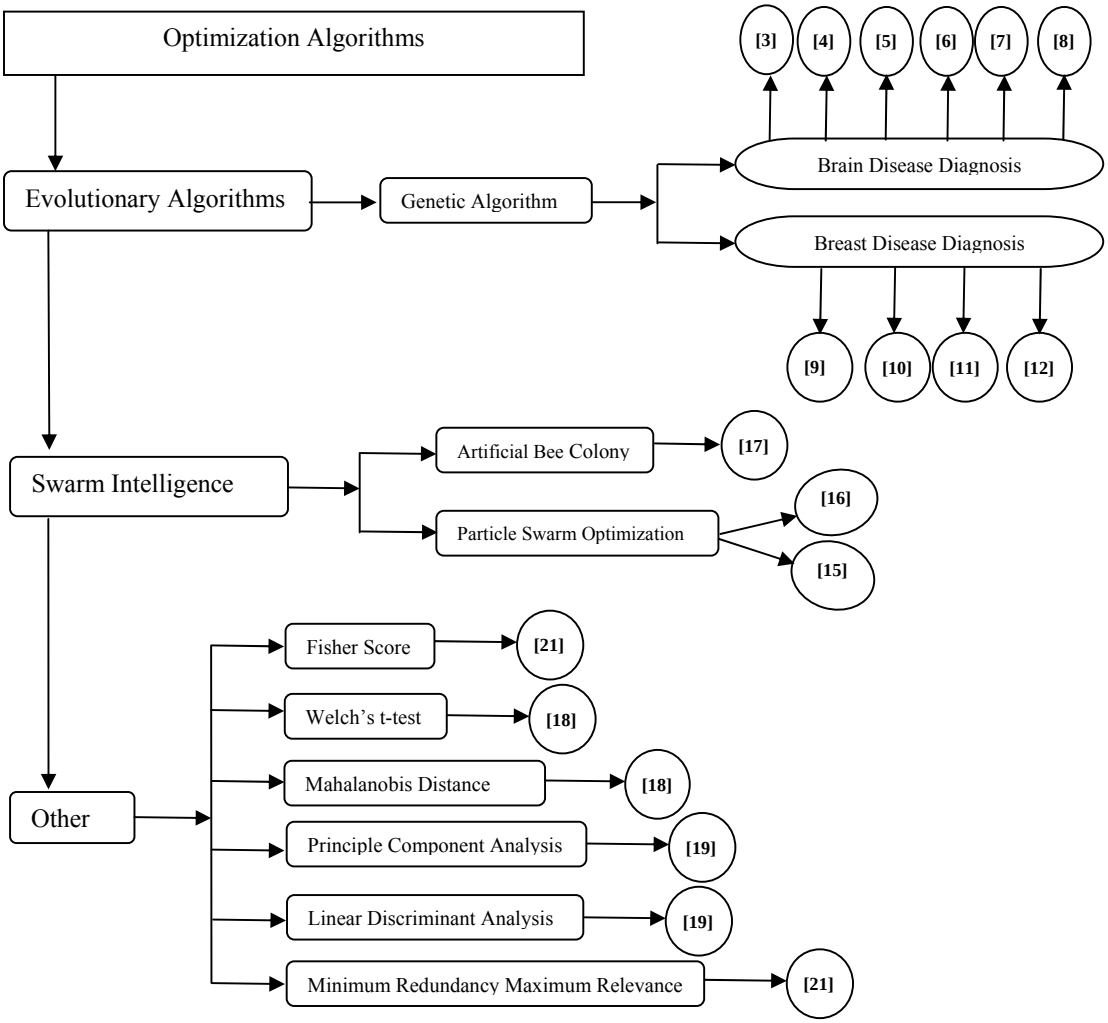

Figure 1. Classification of optimization algorithms for Feature Selection

III.TEACHING LEARNING BASED OPTIMIZATION (TLBO)

Existing feature optimization algorithms typically require many sample images to estimate precisely and are time consuming. System processing time increases unusually when the quantity of features increases. To handle this stage, we are focusing on Teaching Learning Based Optimization. Table V summarizes the TLBO variants and its applications from the reviewed studies.

TABLE V. SUMMARY OF TLBO VARIANTS FOR FEATURE SELECTION IN VARIOUS APPLICATIONS

Author	Application	TLBO Variant
Naga Srinivasu et al. [23]	Automated Brain MRI image segmentation	TLBO& GA
Abhilasha Wakde et al. [24]	Face Detection	Partial Feature and TLBO
Kapil Verma et al. [25]	Face Detection	Multi-Objective TLBO
Gulave Sukdev Madhav et al. [26]	Face Detection	TLBO
Malkhede Seema Krishna et al. [27]	Fingerprint Recognition	TLBO
Baljit Singh Khehra et al. [28]	Image Segmentation	TLBO and Fuzzy Entropy
Vipin Wani et al. [29]	Image Fusion Technique	Wavelet Transform & TLBO
Agrawal et al. [30]	Iris recognition system	TLBO
Hongjian Zhang et al. [31]	Fault detection in train centre plate bolt loss from bolts region images	Improved TLBO
Suresh C. Satapathy et al. [32]	Optimal Feature Selection (Cancer Data)	Rough Sets & TLBO
Chereddy Srinivasa Rao et al. [33]	Automatic Medical Image Segmentation	AUTOTLBO
Suresh chandra Satapathy et al. [34]	Global Optimization Problem	Orthogonal TL BO

The working of TLBO is split into two branches, “Teacher phase” and “Learner Phase”. Learners learn through the teacher in the teaching period. A teacher attempts to enhance the mean result of the class in the subject taught by him based on his potential. Learners raise their familiarity by interaction among themselves in the learner period. A learner correlates arbitrarily with other learners for improving his familiarity.

In the proposed imaging system the feature subset selection is done by TLBO based algorithm. The working of the system is as follows,

- Features are extracted from the medical images collected from health care data centers.
- Extracted Feature vector is given as input to the TLBO based optimal feature selection algorithm for feature reduction.
- Target Image is checked against the reduced feature set by the Classifier for disease detection.

The Overall Framework of the proposed imaging system for feature optimization is as shown in Figure 2.

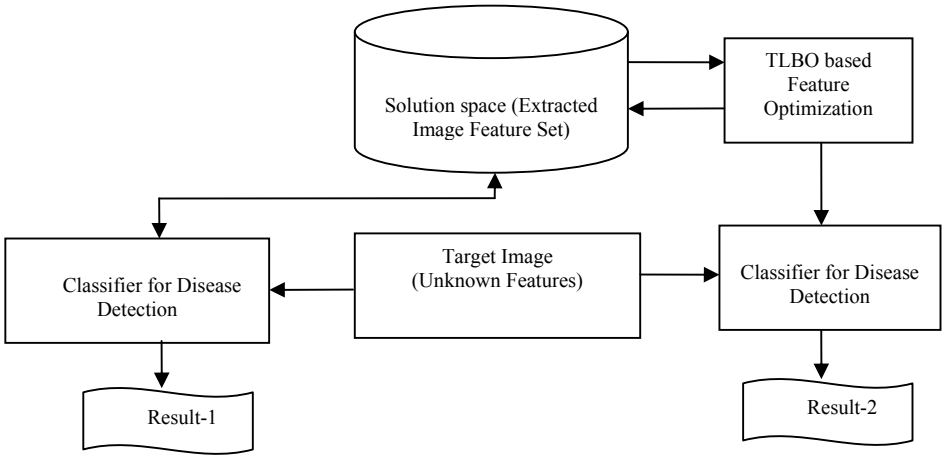

Figure 2. Proposed System with TLBO for Feature Selection

Result-1 is the outcome from the classifier, which takes all the extracted features to check against the target feature set. Whereas result-2 takes only the optimized feature set for the outcome. Result-2 would be very fast and accurate compared to result-1.

IV. CONCLUSION

The key object of this paper is to compare a variety of algorithms for the selection of potential feature vectors from medical images to assist future evolution for more effective image-based disease diagnosis based on the evolutionary algorithms. The proposed technique will contributes to the better diagnosis than the existing techniques. We want to extend the same system to diagnosis any disease as a future enhancement.

REFERENCES

[1] Imane nedjar, Mostafa el habib daho and Nesma settouti, "Random forest Based Classification of medical X-ray images using a genetic algorithm for feature selection", Journal of Mechanics in Medicine and Biology, vol. 15, no. 2, 2015.

[2] D. Asir Antony Gnana Singh, E. Jebamalar Leavline, R. Priyanka and P. Padma Priya , "Dimensionality Reduction using Genetic Algorithm for Improving Accuracy in Medical Diagnosis", International Journal of Intelligent Systems and Applications (IJISA), vol. 8, no.1, pp.67-73,2016.

[3] A. Padma and Dr. R. Sukanesh, "Automatic Diagnosis of Abnormal Tumor Region from Brain Computed Tomography Images Using Wavelet Based Statistical Texture Features", International Journal of Computer Science, Engineering and Information Technology (IJCSEIT), vol. 1, no. 3, 2011.

[4] Savas Okyay, Nihat Adar, Kemal O zkan, "Feature Selection on MR Images using Genetic Algorithm with SVM and Naive Bayes Classifiers", International journal of intelligent systems and applications in engineering (IJISAE) , 4(Special Issue), 170–174, 2016.

[5] I. V. Accamma, H. N. Suma, M Dakshayini, "A Genetic Algorithm Based Feature Selection Technique for Classification of Multiple-Subject fMRI Data", IEEE International Advance Computing Conference (IACC), 2015.

[6] H. Shahamat , A. A. Pouyan , "Feature selection using genetic algorithm for classification of schizophrenia using fMRI data", Journal of AI and Data Mining , vol. 3, no. 1, pp. 30-37, 2015.

[7] Ahmed Kharrat, Mohamed Ben Messaoud, Nacéra Benamrane, Mohamed Abid ," Genetic Algorithm for Feature Selection of MR Brain Images Using Wavelet Cooccurence", International Conference on Signal and Information Processing (ICSIP 2010), 2010.

[8] Ahmed Kharrat, Karim Gasmi, Mohamed Ben Messaoud, Nacéra Benamrane," Medical Image Classification Using an Optimal Feature Extraction Algorithm and a Supervised Classifier Technique", International Journal of Software Science and Computational Intelligence, vol. 3, no. 2, pp. 19-33, 2011.

[9] S.Sasikala, Dr.S.Appavu alias Balamuruganb and Dr.S.Geetha, "A Novel Feature Selection Technique for Improved Survivability Diagnosis of Breast Cancer", 2nd International Symposium on Big Data and Cloud Computing (ISBCC'15), pp. 16-23, 2015.

[10] G.Ravi Kumar, Dr.G.A.Ramachandra and K.Nagamani , "An Efficient Feature Selection System to Integrating SVM with Genetic Algorithm for Large Medical Datasets", International Journal of Advanced Research in Computer Science and Software Engineering , vol. 4, no. 2, 2014.

[11] Shokoufeh Aalaei, Hadi Shahraki, Alireza Rowhanimanesh and Saeid Eslami , "Feature selection using genetic algorithm for breast cancer diagnosis: experiment on three different datasets", Iranian Journal of Basic Medical Sciences, vol. 19, pp. 476-482,2016.

[12] L. Tesa, Daniel Smutek, and Jan Jiskra, "Genetic Algorithms for Thyroid Gland Ultrasound Image Feature Reduction", vol. 3612, pp. 841–844, Springer, Heidelberg, 2005.

[13] Shenshen Sun, Wenbo Li , Yan Kang "Lung Nodule Detection Based on GA and SVM",8th International Conference on Biomedical Engineering and Informatics (BMEI),2015.

[14] Xiabi Liu, Ling Ma, Li Song, Yanfeng Zhao, Xinming Zhao, and Chunwu Zhou, "Recognizing Common CT Imaging Signs of Lung Diseases Through a New Feature election Method Based on Fisher Criterion and Genetic Optimization", IEEE Journal of Biomedical and Health Informatics,vol. 19, no. 2, 2015.

[15] Sasi Kumar M, and Dr. Y.S. Kumaraswamy, "Medical Image Retrieval System Using PSO for Feature Selection", International Conference on Computational Techniques and Mobile Computing (ICCTMC'2012), pp. 14-15, 2012.

[16] Pooja Malviya, Amit saxena, "An Improved Image Fusion Technique based on Texture Feature Optimization using Wavelet Transform and Particle of Swarm Optimization (POS)", International Journal of Computer Applications vol. 101,no.6, pp. 0975-8887, 2014.

[17] Vartika Agrawal, Satish Chandra , "Feature Selection using Artificial Bee Colony Algorithm for Medical Image Classification",IEEE,2015

[18] Shuihua Wang, Yudong Zhang, Xiaojun Yang, Ping Sun, Zhengchao Dong , Aijun Liu and Ti-Fei Yuan, "Pathological Brain Detection by a Novel Image Feature—Fractional Fourier Entropy", Entropy, 17, 8278–8296, 2015.

[19] V.P.Gladis Pushpa Rathi1 and Dr.S.Palani, "Brain Tumor MR Image Classification With Feature Selection And Extraction Using Linear Discriminant Analysis", International Journal of Information Sciences and Techniques (IJIST), vol. 2, no.4, 2012.

[20] F. Shirbani1 and H. Soltanian Zadeh , " Fast SFFS-Based Algorithm for Feature Selection in Biomedical Datasets", Amirkabir International Journal of Science& Research (Electrical & Electronics Engineering) , vol. 45, no. 2, pp. 43- 56, 2013

[21] Vamsidhar Enireddy, Dr.D.V.V.S.PhaniKumar, Dr. Gunna Kishore," Application of Fisher Score and mRMR Techniques for Feature Selection in Compressed Medical Images", International Journal of Engineering and Technology (IJET), vol. 7,no. 6, 2016.

[22] R. Venkata Rao , "Review of applications of TLBO algorithm and a tutorial for beginners to solve the unconstrained and constrained optimization problems", Decision Science Letters, vol. 5, pp. 1–30, 2016.

[23] P. Naga Srinivasu, G. Srinivas and T. Srinivas Rao, "An automated Brain MRI image segmentation using Generic Algorithm and TLBO", IJCTA, 9(32), pp. 233-241), 2016.

[24] Abhilasha Wakde, Virendra Shrivastava, "The Improved Performance of Face Detection Based on Partial Feature and TLBO", International Journal of Emerging Technology and Advanced Engineering, vol. 6, no. 9, 2016.

[25] Kapil Verma, Akash Mittal, Yogendra Kumar Jain, "A Hybrid method of face detection based on Feature Extraction using PIFR and Feature Optimization using TLBO", Journal of Engineering Research and Applications, Vol. 6, Issue 1, pp.145-150 (Part - 4) January 2016.

[26] Gulave Sukdev Madhav, Surendra Vishwakarma , " Improve the Performance of Face Recognition Using Feature Based and Teacher Learning Based Optimization Techniques", International journal of Master of Engineering Research and Technology vol. 2, no. 10, 2015.
[27] Malkhede Seema Krishna , Surendra Vishwakarma , " Improve the Performance of Fingerprint Recognition Using Feature Selection and Teacher Learning Based Optimization (TLBO)", International journal of Master of Engineering Research and Technology, vol. 2, no. 10,2015.
[28] Baljit Singh Khehra, Amar Partap Singh Pharwaha , "Image Segmentation using Teaching-Learning-based Optimization Algorithm and Fuzzy Entropy", 15th International Conference on Computational Science and Its Applications,2015.
[29] Vipin Wani,Pankaj Kawadkar, "An Improved Image Fusion Technique Based On Texture Feature Optimization Using Wavelet Transform and Teacher Learning Optimsation Technique (TLBO)", International Journal of Modern Trends in Engineering and Research (IJMTER), vol. 2, no. 7, 2015.
[30] Shikha Agrawal , Shraddha Sharma, Sanjay Silakari , "Teaching Learning Based Optimization (TLBO) Based Improved Iris Recognition System", Advances in Intelligent Systems and Computing , vol. 366, pp. 735-740, 2015.
[31] Hongjian Zhang , Ping He and Xudong Yang, "Fault Detection Based on Multi-Scale Local Binary Patterns Operator and Improved Teaching-Learning-Based Optimization Algorithm", ww.mdpi.com/journal/symmetry,1734-1750, 2015.
[32] Suresh C. Satapathy, Anima Naik, Parvathi K, "Rough set and teaching learning based optimization technique for optimal features selection", Central European Journal of Computer Science, vol. 3, no. 1, pp. 27-42, 2013.
[33] Chereddy Srinivasa Rao, Kanadam Karteeka Pavan1, Allam AppaRao, "An Automatic Medical Image Segmentation using Teaching Learning Based Optimization", Proc. of Int. Conf. on Advances in Computer Science, AETACS, 2013.
[34] Suresh Chandra Satapathy, Anima Naik and K Parvathi, "teaching learning based optimization based on Orthogonal design for solving global optimization problems", SpringerPlus, 2013.