Automatic Blood Vessel Segmentation in Retinal Image Based on Mathematical Morphology

Vandana Y. Koli, Ashwini G. Andurkar, Harsha S. Jain

Abstract— Retinal blood vessels detection or segmentation is important according to ophthalmologist. To diagnose the retinal disease or to avoid the vision loss, regular checkup of retinal blood vessels is necessary. This regular checkup provides the information about the changes of blood vessels. This changes are like swelling, narrowing of blood vessels etc. The automatic segmentation of blood vessels helps in the diagnosis of retinal diseases. In this work two approaches are used for vessel segmentation. First one is segmentation using morphology with Thresholding and second is segmentation using morphology with Fuzzy-C-Means clustering. Both approaches are unsupervised methods. The segmentation result of these methods is approximately same but there is one difference. The first one technique provides better result for major vessel while second provides good result for minor vessels. This system designed to resolve the problem of ophthalmologist by developing two algorithms.

Index Terms—Retinal Blood Vessels, Fuzzy-C-Means, Mathematical Morphology, Thresholding

I. INTRODUCTION

Neural cells composed thin tissue located in the posterior portion of the eye is called as **Retina.** Retina includes the different or unique patterns of blood vessels. These blood vessels are generally unchanged from birth until death but due to some diseases they may cause change. For example, **Hypertansion,** high blood pressure causes the blood vessels to narrow, leak and harden over time as these vessels subjected to continued excessive blood pressure. In some case, this can cause optic nerve to swell and result in vision loss. This kind of eye disease called as hypertensive retinopathy. Also, retinal vein occlusion (RVO), Central retinal artery occlusion (CRAO) and diabetic retinopathy are some eye diseases which provide vision loss. To prevent the vision loss regular examination of eye plays a vital role in treatment. So the automatic blood vessel segmentation of retinal blood vessel is one of the most important processes.

As previously mentioned retinas have unique patterns are also used as **Biometric Identifier**. This kind of biometric identifier uses a technology is called as retinal scanning. Analysis of retinal blood vessel used to find characteristic patterns. This is usually used in environment that requires high degrees of security. This is a well known technology, but still in a prototype development stage and still commercially unavailable.Manual delineation of vessels becomes tedious or even impossible when the number of vessels in an image is large or when large numbers of images are acquired. So it is necessary to segment the blood vessels automatically. The proposed system is implemented and tested using **MATLAB 7.11.0 (R2010b)**. Developed approach uses retinal images from **DRIVE** database. This system uses **Mathematical Morphology** to extract retinal blood vessels from the background. These extracted blood vessels then applied to **Thresholding** and **Fussy-C-means** clustering for segmentation purpose. The performance of these two segmentation approaches is evaluated, by using **Accuracy**, **Sensitivity** and **Specificity**, such kind of parameter.

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Miss. Vandana Koli, Department of Electronics & TeleCommunication, Government College of Engineering, Jalgaon, India.
Mrs. Ashwini Andurkar, Department of Electronics & TeleCommunication, Government College of Engineering, Jalgaon, India.
Miss. Harsha Jain, Department of Electronics & TeleCommunication, Government College of Engineering, Jalgaon, India.

II. MATHEMATICAL MORPHOLOGY

Origin of the morphology is in biology which deals with the form and structure of animals and plants. Here the term mathematical morphology used for extraction of image component. Prior to start with the discussion of proposed method is necessary to understand the basics of mathematical morphology.

A. Set Theory

Mathematical morphology provides number of operators to contribute in image processing; all are based around some simple mathematical concept from set theory. May be that's why is called as **Mathematical** Morphology. Some basic operations from set theory are as

I. If a= (a_1, a_2) is an element of A, then write as $a \in A$
II. If a is not an element of A , write as $a \notin A$
III. The set with no elements is called the null or empty set and is denoted by the symbol = $\varnothing$.
IV. If every element of a set A is also an element of another set B, then a is said to be a subset of B, denoted as $A \subseteq B$
V. The **union** of two sets A and B, denoted by $C= A \cup B$. Is the set of all elements belonging to either A, B or both
VI. The **intersection** of two sets A and B, denoted by $D=A \cap B$; Is the set of all elements belonging to both A and B

All these basic operations are also useful to calculate the evaluation parameters, such as accuracy, sensitivity and specificity.

B. Basic Morphological Operation

The morphological theory views a binary image as a set of foreground pixels. Means the set operations are directly applied to the binary image sets [5]. The fundamental operations of morphological theory are **Dilation** and **Erosion.** The dilation operation is used to grow or thickens objects in image while erosion is used to shrinks or thins objects.

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Both these thickening and thinning is controlled by a shape which is referred as **Structuring Element (SE)**. The structuring element is created in MATLAB using "**strel**" function. Maximum numbers of SE are available like disk, diamond, line, rectangle etc [6].

The first operand used in both of this operation or other which are combinations of these two is image and the second operand is structuring element. A and B used in following equation are image and structuring element respectively.

Mathematically both of these operations are written in the following manner

$$D(A, B) = A \oplus B = \{Z \mid (B^{\wedge})_z \cap A \neq \varnothing\} \qquad 1$$

Where in equation 1 "D" used to show the dilation. The dilation operation denoted by a symbol $\oplus$, is called as minkowski addition.

$$E(A, B) = A \ominus B = \{Z \mid (B)_z \subseteq A\} \qquad 2$$

Where in equation 2 "E" used to show the erosion. The dilation operation denoted by a symbol $\ominus$, is called as minkowski subtraction.

Combination of dilation and erosion generates two new morphological operations are **Opening** and **Closing**. Opening is denoted by "o" and Closing denoted by "•". Both equations are as

Opening

$$A \circ B = (A \ominus B) \oplus B \qquad 3$$

Closing

$$A \bullet B = (A \oplus B) \ominus B \qquad 4$$

C. Gray Scale Morphology

The Dilation and Erosion used for binary images are defined as maxima and minima for gray scale images.

Mathematical definition of dilation for gray scale image is as [1]

$$A \oplus B = A1(x,y) = \max(A(x-i, y-j)) + B(i,j)\; i,j \in B \qquad 5$$

Mathematical definition of erosion for gray scale image is as

$$A \ominus B = A1(x,y) = \min(A(x-i, y-j)) + B(i,j)\; i,j \in B1 \qquad 6$$

The expressions for opening and closing gray scale images have the same form as their binary counterparts. Opening suppresses brighter details which are smaller than the structuring element while closing suppresses dark details which are smaller than structuring element [5].

III. PROPOSED SYSTEM

The input images used for the segmentation are obtained from DRIVE database which is publically available on http://www.isi.uu.nl/Research. The key feature of this work is morphological operation. And that processed image is then goes for segmentation. In this work two approaches are used for the segmentation purpose thresholding and FCM clustering. So two different kinds of results are generates. The developed segmentation model is shown in fig. 1.

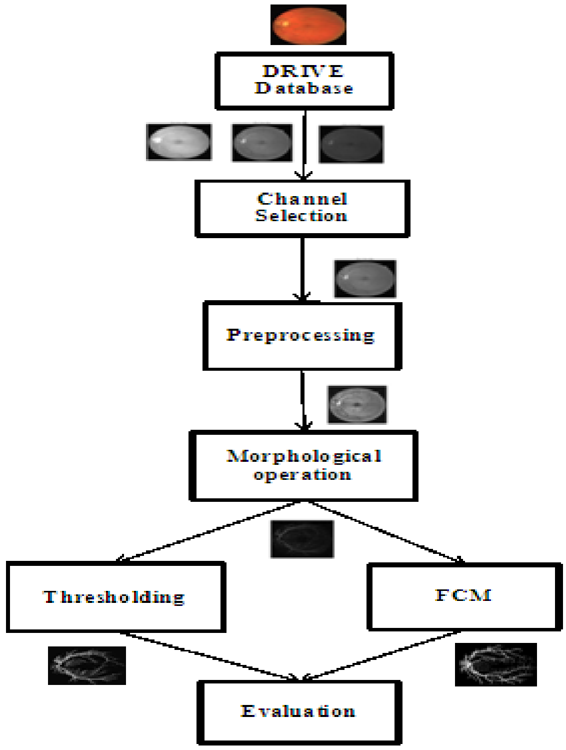

Fig. 1 Developed Segmentation Model

IV. DRIVE DATABASE

Images used for segmentation purpose are from DRIVE (Digital Retinal Images for Vessel Extraction) database. This database consists of 40 color funds photographs and their ground truth images. For first 20 images have two ground truth images for each image, which are obtained by two different specialists. In this work for first 20 images the performance evaluation is done using GT images created by first specialist.

All images in DRIVE database are digitized using a Cannon CR5 non-mydriatic 3CCD camera with a 45 degree field of view. Each image is captured using 24-bits per pixel at the image size of 565×584. These images were labeled by hand, to produce ground truth vessel segmentation [4].

First image among the DRIVE database is selected for the to show the development of proposed algorithm. RGB input image is taken from database. That image is shown in fig. 1.

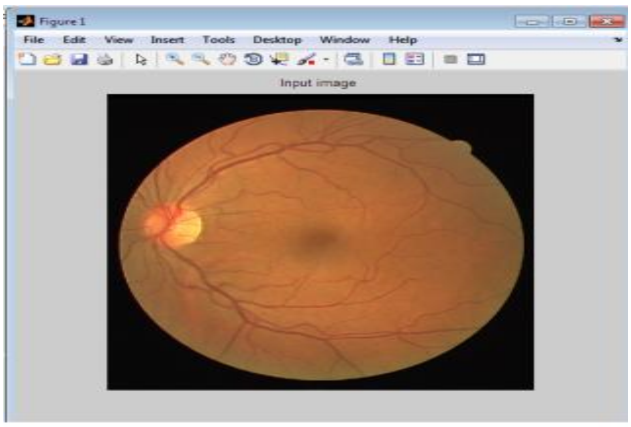

Fig. 2 RGB Input Image

V. CHANNEL SELECTION

As DRIVE database will provide RGB image which is not perceptually uniform and Euclidian distance in 3D RGB space do not correspond to color difference as perceived by humans, so these images are not directly used for vessel segmentation. So the next task is to separate out all the three components from RGB image [1].

All of these separate components are liable to use for further processing but according to the histogram, green component image provides better contrast between vessels and background image shown in fig. 3. For segmentation purpose it is necessary to obtain the contrast between blood vessels and background image. So the green channel is selected for further processing. Selected green component image is shown in fig. 4.

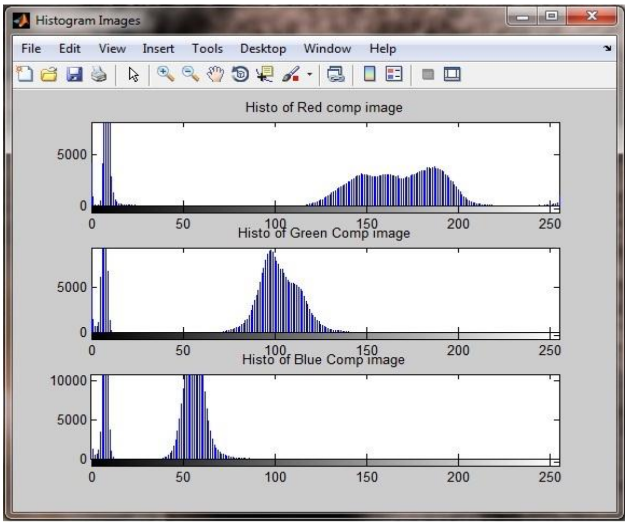

Fig. 3 Histograms of Red, Green and Blue Component

Fig. 4 Green Channel

VI. PREPROCESSING

Low contrast images could occur often due to several reasons, such as poor or non uniform lightning condition, nonlinearity or small dynamic range of the imaging sensor, i.e. illumination is distributed non-uniformly within the image. Therefore it is necessary to deepen the contrast of these images to provide better transformation representation for subsequent image analysis steps. CLAHE technique is adopted to perform the contrast enhancement. This approach consists of processing small regions of image are called as tiles. In this work the size of tiles is [8 8]. The green component image is then processed for the enhancement. The enhanced image using CLAHE is shown in fig. 5 [5].

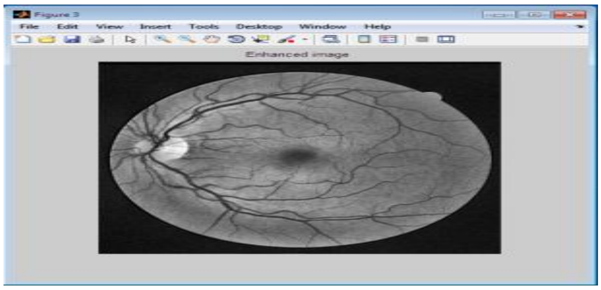

Fig. 5 Enhanced Image

VII. IMAGE SEGMENTATION

By using closing, which is gray scale morphological operation the segmentation is done. Two kinds of disk structuring elements (SE) are used. One structuring element is of higher value and another one is of lower value. The higher value is eight and lower is one. Firstly the enhanced image is closed by using higher structuring element. And also the same enhanced image is closed by lower structuring element. Flat structuring element is used for morphological operation.

The image which is closed by lower structuring element is subtracted from the image closed by higher structuring element. Same size of image is obtained from this subtraction. And the output image contains extracted blood vessel from background. To eliminate the background two approaches are used which gives different result. Both the closed images are shown in fig. 6. Fig. 7 shows the extracted blood vessels from background.

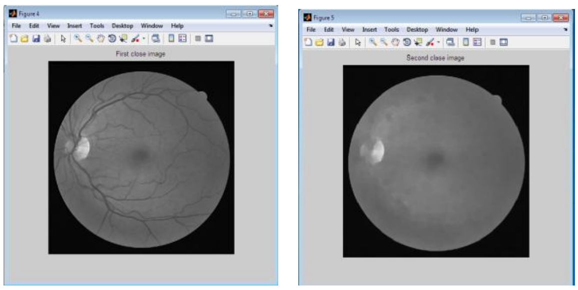

Fig. 6 Closed image using SE=1 and SE=8(from left to right)

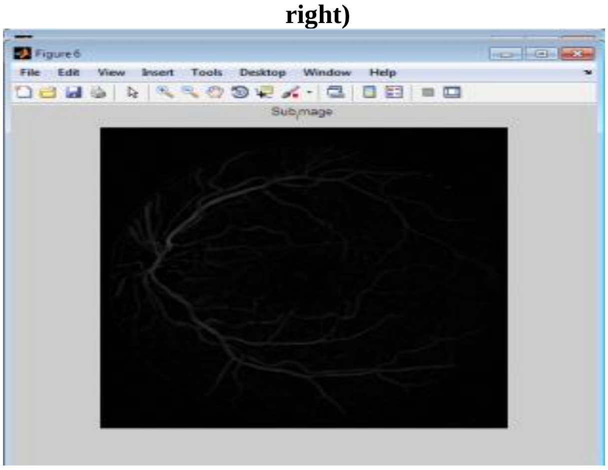

Fig. 7 Subtracted Image

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A. Thresholding

The extracted blood vessel image is applied to the thresholding to eliminate the background [2]. After thresholding application will get the properly segmented image. The obtained output image is the binary image. In this work global thresholding is used. This approach is capable to choose thresholding automatically based on image data [5]. In this work the resulted threshold value is near to the midpoint of gray scale. The result of thresholding the image obtained from morphological operation is shown in fig. 8.

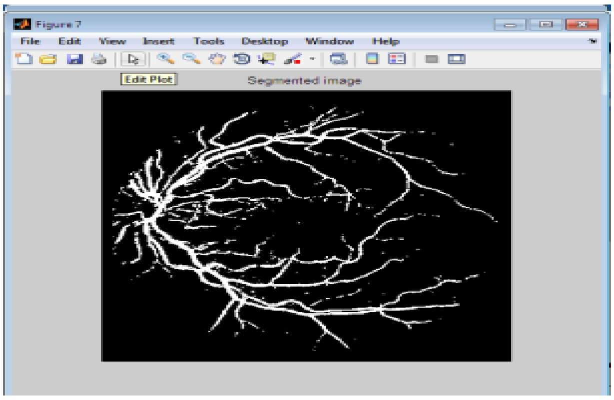

Fig. 8 Segmented Image After Thresholding

B. Fuzzy-C-Means Clustering

Extracted blood vessel image is applied to clustering technique for proper segmentation. FCM computes cluster centers or centroids by minimizing the dissimilarity function with the help of iterative approach [3]. By updating the cluster centers and the membership grades for individual pixel, FCM shifts the cluster centers to the "right" location within set of pixels. To accommodate the introduction of fuzzy partitioning, the membership matrix (U) = [uij] is randomly initialized according to equation 7, where uij being the degree of membership function of the data point of ith cluster xi. The performance index (PI) for membership matrix U and Ci's used in FCM is given equation 8. To reach a minimum of dissimilarity function there are two conditions. These are given in Equation 9 and Equation 10 [8].

$$\sum_{i=1}^{c} u_{ij} = 1, \forall j = 1,\ldots,n \qquad 7$$

$$J(U, c_1, c_2, \ldots, c_c) = \sum_{i=1}^{c} J_i = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^{\ m} d_{ij}^{\ 2} \qquad 8$$

$$c_i = \frac{\sum_{j=1}^{n} u_{ij}^{\ m} x_j}{\sum_{j=1}^{n} u_{ij}^{\ m}} \qquad 9$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{d_{ij}}{d_{kj}} \right)^{2/(m-1)}} \qquad 10$$

The data obtained from clustering is then converted into 2D matrix. From this matrix a binary image is constructed. That segmented image is shown in fig. 9.

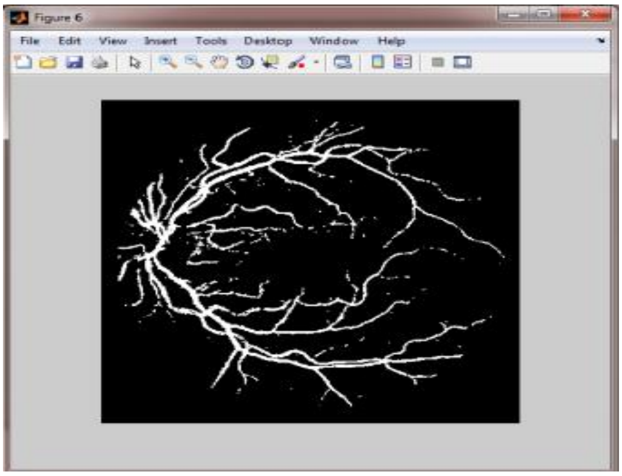

Fig. 9 Segmented Image Using FCM

VIII. EVALUATION PARAMETER

The evaluation of segmentation is pixel based measures. That means the evaluation score is computed based on the number of correctly or incorrectly classified pixels. This measurement is done by using true positive (TP), true negative (TN), false positive (FT), false negative (FN). Where true positive indicates the correctly identified vessel pixel, false positive indicates the incorrectly identified vessel pixels, false negative incorrectly identified non vessel pixels and true negative is correctly identified non vessel pixels.

The parameter which is used to detect vessel pixel is sensitivity. It is the ratio of true positive to the summation of true positive and true false negative value. Specificity is used to detect non vessel pixel. It is the ratio of true negative to the summation of true negative and true false positive value. Accuracy is the third parameter which provides the ratio of total well classified pixels. It is the ratio of sum of correctly classified vessel pixels and true negative is correctly identified non vessel pixels to the total number of pixel present in the segmented image [7]. All these parameters are mathematically formulated as [2]

$$\text{Sensitivity} = \frac{TP}{TP+FN} \qquad 11$$

$$\text{Specificity} = \frac{TN}{TN+FP} \qquad 12$$

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \qquad 13$$

In MATLAB these parameters are calculated using some simple operation of set theory. This pixel based measurement is possible only when ground truth image of respective image is available. DRIVE database will include retinal images and their ground truth image so that's why this pixel based evaluation is possible in this case.

IX. PERFORMANCE ANALYSIS OF SEGMENTATION

A. Morphology with Thresholding

In previous discussion both algorithms are explained using only one image. The result of this algorithm on other image is shown in fig.10. These images include input image, segmented image and ground truth image from left to right.

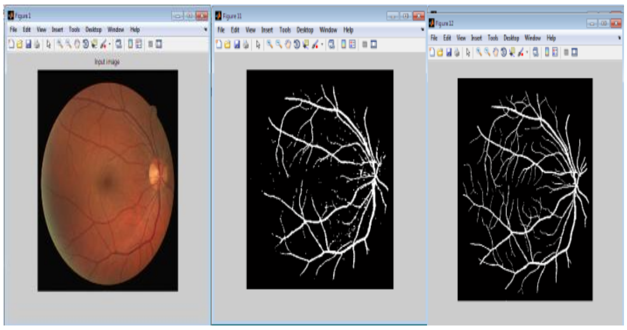

Fig. 10 Result Of First Algorithm

The evaluation parameter of some random images from database is calculated which is shown in table 1. From the table 1average result of this method is 80% Specificity, 76% Sensitivity and 72% Accuracy.

Table 1 Evaluation Parameter of First Method

Database Images	Sensitivity	Specificity	Accuracy
Image 1	0.7764	0.8111	0.7284
Image 2	0.7654	0.8907	0.7523
Image 3	0.7163	0.824	0.6937
Image 4	0.7756	0.7695	0.7102
Image 5	0.8172	0.7194	0.7134
Image 6	0.7708	0.7632	0.7034
Image 7	0.8187	0.8604	0.7801
Image 8	0.7721	0.7788	0.7108
Image 9	0.7908	0.7882	0.7284
Image 10	0.778	0.7743	0.7139
Image 11	0.7461	0.8316	0.7145
Image 12	0.709	0.8745	0.7048
Image 13	0.7323	0.8634	0.7202
Image 14	0.7651	0.8473	0.7305
Image 15	0.7781	0.7873	0.7291

B. Morphology with FCM

. The result of this algorithm on other image is shown in fig.11. These images include input image, segmented image and ground truth image from left to right. From the table 2 it is clear that FCM algorithm provides 76% sensitivity, 84% specificity and 71% Accuracy.

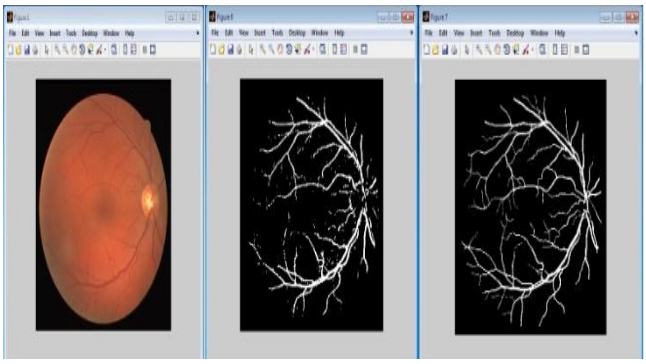

Fig. 11 Result Of Second Algorithm

Table 2 Evaluation Parameter of Second Method

Database Images	Sensitivity	Specificity	Accuracy
Image 1	0.7464	0.8515	0.7229
Image 2	0.7246	0.9306	0.7337
Image 3	0.7311	0.8324	0.7057
Image 4	0.7081	0.9121	0.7801
Image 5	0.8508	0.8508	0.6687
Image 6	0.7966	0.758	0.7198
Image 7	0.7675	0.7335	0.7213
Image 8	0.8047	0.871	0.7737
Image 9	0.7636	0.79	0.7102
Image 10	0.7519	0.8034	0.7074
Image 11	0.7825	0.805	0.7299
Image 12	0.799	0.9025	0.7148
Image 13	0.8023	0.8934	0.6902
Image 14	0.7651	0.9063	0.7105
Image 15	0.7581	0.8173	0.706

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AUTHORS PROFILE

Miss Vandana Koli received her Bachelor of Engineering degree in Electronics and Tele-Communication from Government College of Engineering, Jalgaon, India., in 2011. Her research interest includes digital image processing. At present she is engaged in pursuing Master of Engineering in Electronics and Tele-communication with specialization in Digital Systems from Government College of Engineering, Jalgaon, India.

Mrs. Ashwini Andurkar received her Bachelor of Engineering degree in Electronics and Tele-Communication from Marathwada University, India, in 1993. She received her Master of Engineering degree with specialization in Electronics from Dr. Babasaheb Ambedkar Marathwada University, in 2000. Since 2008, he has been with the Government College of Engineering, Jalgaon, where she is currently as Assistant Professor. Her main area of interest is Analog Communication, Electromagnetics, Mirowave and Telematics

Miss Harsha Jain received her Bachelor of Engineering degree in Electronics and Tele-Communication from Maratha Vidya Prasarak Samaj‟s K.B.T. College of Engineering, Nasik, India, in 2011. Her research interest includes digital signal processing, biomedical signal processing, electronic circuit design and its applications. At present she is engaged in pursuing Master of Engineering in Electronics and Tele-communication with specialization in Digital Systems from Government College of Engineering, Jalgaon, India

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