FFT Based Image Registration using Corner Response

R. Kokila, and P. Thangavel

***Abstract*—** We present a corner response based image registration technique. Fast Fourier Transform (FFT) based scheme combined with corner response is able to recover the scale and rotation parameters. We have tested the proposed technique with different image sets and found that this scheme works comparable to that of other FFT based methods.

***Keywords*—** Corner response, Fast Fourier transform, Log polar transform, Phase correlation.

I. Introduction

IMAGE registration is an important tool to estimate geometric transforms in images. When two or more images of the same scene taken at different geometric viewpoint, or by a different image sensor that can be integrated or compared using image registration. Image registration [18] is widely used in different fields such as remote sensing for multispectral classification, environmental monitoring, change detection, creating super-resolution images and integrating information into geographic information systems (GIS). In medical applications it is used for combining data from different modalities such as computer tomography and magnetic resonance imaging (MRI). Image registration is also used in cartography for map updating and in computer vision for target localization and automatic control.

Image registration can be broadly classified into area based and feature based methods. Feature based methods deal with detecting the feature points in the two images and register them. Color gradients, edges, geometric shape, contour, image gradient are said to be the features. To extract features from the image and then the scale and rotation parameters, Lowe [11] proposed scale invariant feature transform (SIFT) method. Mikolajczyk and Schmid [13] combined Harris corner detection [3] and Laplacian-of-Gaussian in order to extract features from the images. Jackson and Goshtasby [4] proposed a method using the projective constraint for registering video frames of a scene consisting of flat background, moving objects and three dimensional structures captured by a moving frame.

When an image is not rich in details, then the features in it will be difficult to distinguish from each other, in this case the area based approach will be quiet useful. Normalised cross correlation [8] is a widely used approach in the area based method. Kybic [7] proposed a method to estimate the uncertainty of area based image registration algorithm on a particular pair of images. Wang et al. [17] employed a probability density gradient based interest point detector to extract the stable point features. They proposed global parallax histogram based filter to discard the outlier induced by classical correlation method. Lin et al. [9] proposed a method for automatic registration. In this, they first applied Harris operator to extract the corner features after that Canny operator is implemented to detect the image edges. The correlation between the image pairs yields the corner points. The affine transformation between the image pair is established, which calculates the parameters, according to that the images are registered.

Two images may differ from each other by its scale, rotation and translation that can be determined by using fast Fourier transform (FFT) method [14]. The Fourier method searches for the optimal match based on the information in the frequency domain. Because of this distinct feature it differs from other registration strategies. Matungaka et al. [12] proposed an adaptive polar transform instead of log-polar transform for registering the images. They combined the adaptive polar transform with projection transform along with matching mechanism to recover the scale, rotation and translation. Tzimiropoluos et al. [16] have reported FFT based registration scheme with image gradients. They replaced the image functions with the complex gray level edge maps and then performed FFT. Then resampled it on the log-polar grid and then used normalised gradient correlation (NGC) to detect the geometric transformations.

Krish et al. [5] introduced a new feature based image registration algorithm that detects the scale and rotation and then it is matched using Hough transform. Once the correspondence between the feature are matched then the transformation parameters are estimated using non linear least square and standard RANSAC. Gonzalez [2] proposed a novel phase correlation technique to estimate the geometric transformation. Thangavel and Kokila [15] proposed an extension of FFT based image registration.

In this paper, we propose corner response based image registration. Corner response from both the source and target image is extracted, to this phase correlation is applied in order to recover the scale, rotation and translation parameters. The paper is organised as follows: in Section II we have described about corner response detection in detail. Section III discusses

R. Kokila is with the Department of Computer science, University of Madras, Chepauk, Chennai-600 005, India. (e-mail:kok_oc25@yahoo.co.in).

P. Thangavel is with the Department of Computer science, University of Madras, Chepauk, Chennai-600 005, India. (Corresponding author's phone: 91-44-25399502; e-mail:thangavelp@yahoo.com).

about FFT based image registration. Algorithm is presented in Section IV. Experimental results are described in Section V. Conclusion is drawn in Section VI.

II. Corner response

In this section we review corner response [3] detection scheme for the image registration. When an image is represented with its edges, such as the curved lines and texture edges, will be different for source image and target image. So it will not be easy to track it, in order to overcome this problem the corner response is implemented. Corner feature is also referred as interest point, as image feature characterized by their high intensity change in the horizontal and vertical directions. Corners are also used in shape analysis and motion analysis. Let I be an image and their computed x and y derivatives $(I_x, I_y)$are defined as follow as:

$$\boldsymbol{I_x = I \circledast [-1\ 0\ 1] \approx \frac{\partial I}{\partial x};\ I_y = I \circledast [-1\ 0\ 1]^T \approx \frac{\partial I}{\partial y}}$$

The estimated derivatives are multiplied at each and every pixel, can be represented as follows:

$$\boldsymbol{I_{x^2} = I_x \cdot I_x;\ \ I_{y^2} = I_y \cdot I_y;\ \ I_{xy} = I_x \cdot I_y}$$

The product of the derivatives are convolved with Gaussian filter that is defined as follows:

$$S_{x^2} = g(\sigma) \circledast I_{x^2}$$
$$S_{y^2} = g(\sigma) \circledast I_{y^2}$$
$$S_{xy} = g(\sigma) \circledast I_{xy}$$

Where g is an isotrophic Gaussian filter with standard deviation (σ) that is defined as follows:

$$g(\sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}}$$

Define each and every pixel (x, y) the matrix

$$H(x,y) = \begin{bmatrix} S_{x^2} & S_{xy} \\ S_{xy} & S_{y^2} \end{bmatrix}$$

$$H(x,y) = \begin{bmatrix} A & C \\ C & B \end{bmatrix}$$

A measure of corner response at each pixel is defined by

$$R(x,y) = \det\big(H(x,y)\big) - k(trace(H(x,y))^2$$
$$= (A \cdot B - C^2) - k(A+B)^2$$

Where k is an adjustable constant.

Corner response is used to extract only the richer details available in the edges. Corner response image will have stronger response that will be quiet useful to register an image. Lena image is shown in Figure 1(a) and its corresponding gradient and corner response image are shown in Figure 1(b), Figure 1(c) respectively.

III. Fourier Transform Based Image Registration

In this section we review the Fourier transform theory for image registration [14].

A. Translation

Let (x_0, y_0) be the displacement of the two images f_1 and f_2:

$$f_2(x,y) = f_1(x - x_0, y - y_0) \qquad (1)$$

F_1 and F_2 the fourier transforms of f_1 and f_2 respectively, are related as follows:

$$F_2(\omega_1,\omega_2) = F_1(\omega_1,\omega_2) * e^{-2\pi j(\omega_1 x_0 + \omega_2 y_0)} \qquad (2)$$

The corresponding crosspower spectrum is:

$$\frac{F_2(\omega_1,\omega_2)\, F_1^*(\omega_1,\omega_2)}{F_2(\omega_1,\omega_2)\, F_1(\omega_1,\omega_2)} = e^{-2\pi j(\omega_1 x_0 + \omega_2 y_0)} \qquad (3)$$

Here F_1^* is the complex conjugate of F_1. The phase of crosspower spectrum is equal to the phase difference between the images that is guaranteed by the shift theorem. The impulse function is produced by the inverse Fourier transform of the crosspower spectrum that is approximately zero everywhere except at the point of displacement. The location of the impulse function is used to register the two images.

B. Rotation

Let f_2 be a translated and rotated image of $f_1$with the translation (x_0, y_0) and rotation θ_0. Now f_2 can be written as follows:

$$f_2(x,y) = f_1\begin{pmatrix} x\cos\theta_0 + y\sin\theta_0 - x_0\,, \\ -x\sin\theta_0 + y\cos\theta_0 - y_0 \end{pmatrix} \qquad (4)$$

The Fourier transforms F_1 and F_2 of f_1 and f_2 respectively are related by translation and rotation property that can be defined as:

$$F_2(\omega_1,\omega_2) = F_1\begin{pmatrix} \omega_1\cos\theta_0 + \omega_2\sin\theta_0, \\ -\omega_1\sin\theta_0 + \omega_2\cos\theta_0 \end{pmatrix} * e^{-2\pi j(\omega_1 x_0 + \omega_2 y_0)}$$

If the magnitude of F_1 and F_2 are denoted by M_1 and M_2respectively, then we have,

$$M_2(\omega_1,\omega_2) = M_1\begin{pmatrix} \omega_1\cos\theta_0 + \omega_2\sin\theta_0, \\ -\omega_1\sin\theta_0 + \omega_2\cos\theta_0 \end{pmatrix}$$

The magnitudes of M_1 and M_2 are converted to polar co-ordinates, then the Phase correlation is applied to determine the rotation (θ_0)

$$M_1(\rho,\theta) = M_2(\rho,\theta - \theta_0) \qquad (5)$$

C. Scale

When an image is scaled by scale factor a, the relation between the Fourier transform of the image and its scaled image is expressed as follows:

$$F_2(\omega_1, \omega_2) = \frac{1}{a^2} F_1\left(\frac{\omega_1}{a}, \frac{\omega_2}{a}\right) \qquad (6)$$

The above equation can be rewritten in the logarithmic domain as follows:

$$F_2(log\omega_1, log\omega_2) = F_1(log\omega_1 - \log a, log\ \omega_2 - \log a) \quad (7)$$

From the above equation, we can find the scale factor a. Here constant $\frac{1}{a^2}$ is ignored for simplicity.

D. Translation, rotation and scale

When the given two images differ each other with translation, rotation and scaling, their corresponding magnitude spectrum can be represented as follows:

$$M_1(\rho, \theta) = M_2\left(\frac{\rho}{a}, \theta - \theta_0\right) \qquad (8)$$

The respective magnitudes in the log polar co-ordinate system are related as follows:

$$M_2(\log \rho\ , \theta) = M_1(\log \rho - \log a, \theta - \theta_0) \quad (9)$$

The Fourier phase shifting property is used to recover the rotation and scaling between the two images. Once rotation and scaling parameters are recovered then these parameters are applied to image f_2. Now the translational offset between f_1 and f_2 are obtained by applying the standard phase correlation technique.

E. Highpass filter

The following highpass emphasis filter is multiplied with Fourier log magnitude spectra

$$HPF(\xi, \eta) = \big(1.0 - X(\xi, \eta)\big) * \big(2.0 - X(\xi, \eta)\big) \qquad (10)$$

where

$X(\xi, \eta) = [\cos(\pi\xi)\cos(\pi\eta)]$ and $-0.5 \le \xi, \eta \le 0.5$

F. Log-Polar Transform

Log-polar transform is used to convert an image from the cartesian co-ordinate to the polar co-ordinate. The mapping procedure is as follows:

$$\rho = log_{base}\sqrt{(x - x_c)^2 + (y - y_c)^2}$$

$$\theta = tan^{-1}\frac{(y - y_c)}{(x - x_c)}$$

Here, (x_c, y_c) is the center pixel of the transformation in the cartesian co-ordinate, (x, y) denotes the sample pixel in the cartesian co-ordinate and (ρ, θ) denotes the log radius and angular position in the log polar co-ordinate.

IV. Algorithm

In this section, the detailed algorithm for corner response based image registration scheme is presented.

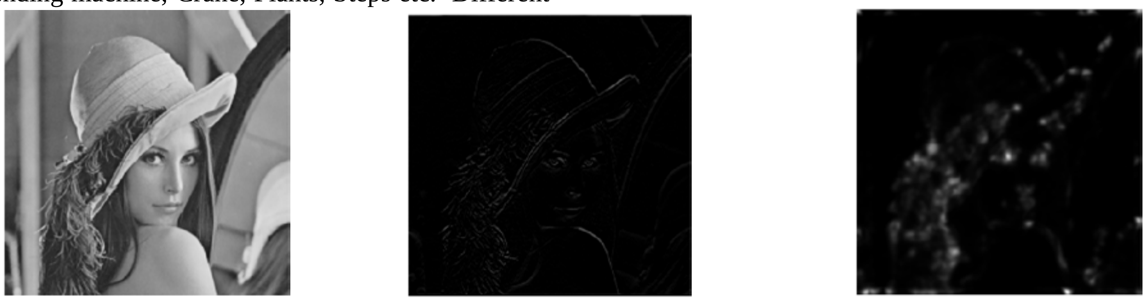
1) The corner response of the source and target images are determined and then zeropadded so that the image size will be $N \times N$ where $N = 2^n$such that $N \ge \max(\ size(source), size(Target))$.
2) Compute the forward Fast Fourier Transform on the corner response of source and target image and take magnitude image of fast Fourier transform.
3) Highpass filter is multiplied with the magnitude image of fast Fourier transform.
4) Fourier magnitude spectrum in the cartesian co-ordinates is mapped to the polar co-ordinates.
5) Phase correlation technique is applied on the log-polar spectra of both the images in order to determine the scale factor and rotation angle.
6) Calculated scale factor and rotation angle are applied to the target image and once again the phase correlation is performed to detect the translation.

V. Experimental Results

First we apply Tukey window as a preprocessing step to both the source image and target image. The corner response for the source image and target image are computed as described in section II and zeropadded the images with size of $N \times N$ where $N = 2^n$such that $N \ge \max(\ size\ (source), size(Target))$. Then the Fourier spectra of both images are computed by using two dimensional FFT. The highpass filter with the transfer function is multiplied with Fourier log magnitude spectrum. After this, the multiplied Fourier spectrum is resampled on log polar grid by using $base = \exp(\log(\frac{N}{2}) * \frac{2}{N})$as a logarithmic base on the log polar domain along with radial axis. The transformed images are phase correlated to detect the location of the impulse. The impulse location will be either x or N-x. The Scale and rotation can be calculated using the following formulas, $scale = \exp(\log(\frac{N}{2}) * \frac{2}{N} * x)$ and $\theta_0 = \frac{180 * y}{N/2}$. 180° ambiguity arises when determining the angle. This can be solved as follows: Let θ_0 be the determined angle. Rotate the spectrum of source image by (θ_0), simultaneously rotate the spectrum of source image by $(180 + \theta_0)$ and again locate the impulse. If the peak value of the inverse Fourier transform of the crosspower spectrum is greater when the angle is θ_0, then the true angle of the rotation is θ_0, otherwise $(180 + \theta_0)$ is the angle of rotation. The computed scale factor and angle are applied to the target image. Phase correlation is applied on the target image and source image to detect the translation.

If the computed scale and rotation is not able to register the source with the target image, then reduce the target image to half of its size and repeat the process. The corner response method might be used twice or thrice to register an image. If the method is used twice then multiply the computed scale factor by 2 otherwise multiply by 4

In order to compute the effectiveness and accuracy of the proposed corner response based image registration scheme, we have used different sets of real time images [20] - [21] such as Vending machine, Crane, Plants, Steps etc. Different rotation and scaling parameters are applied to another set of test images using Matlab such as cameraman, van, clock, fishing boat etc.



(a) (b) (c)

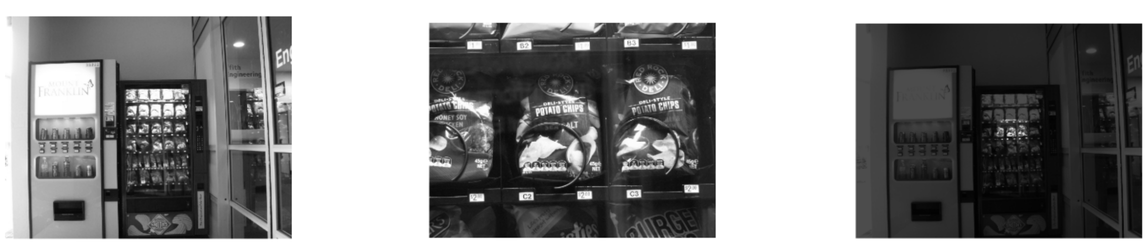
Fig. 1 (a) Lena Image (b) Gradient Image (c) Corner Response Image

(a) (b) (c)

Fig. 2 Image Registration result using the proposed approach on the Clock Image (a) Source Image (b) Target Image (scaled with 6.3 and rotated with 63°) (c) Registration result using the proposed approach

(a) (b) (c)

Fig. 3 Image Registration result using the proposed approach on the Van Image (a) Source Image (b) Target Image (scaled with 5.6 and rotated with 0°) (c) Registration result using the proposed approach



(a) (b) (c)

Fig. 4 Image Registration result using the proposed approach on the Vending Machine Image (a) Source Image (b) Target Image (scaled with 8.83 and rotated with 0°) (c) Registration result using the proposed approach

(a) (b) (c)

Fig. 5 Image Registration result using the proposed approach on the Park Image (a) Source Image (b) Target Image (scaled with 4.99 and rotated with 66.80°) (c) Registration result using the proposed approach

(a) (b) (c)

Fig. 6 Image Registration result using the proposed approach on the Wall Painting Image (a) Source Image (b) Target Image (scaled with 2.88 and rotated with 0°) (c) Registration result using the proposed approach

(a) (b) (c)

Fig. 7 Image Registration result using the proposed approach on the Plant Image (a) Source Image (b) Target Image (scaled with 5.42 and rotated with 0°) (c) Registration result using the proposed approach

TABLE I
SCALE FACTORS AND THEIR CORRESPONDING ROTATIONS ARE RECOVERED BY THE CORNER RESPONSE METHOD (CR) FOR THE STANDARD IMAGES

Input		Clock		Cameraman		Van		Airfield	
Scale	Angle	Scale	Angle	Scale	Angle	Scale	Angle	Scale	Angle
1	5°	1	5.63°	1	5.63°	1	5.63°	1	4.92°
1.5	55°	1.51	54.84°	1.51	54.84°	1.5	54.84°	1.5	54.84°
2	105°	2	105.47°	2	106.88°	2	105.47°	2	104.77°
2.5	155°	2.51	154.69°	2.48	154.69°	2.49	154.69°	2.49	155.04°
3	175°	3.03	174.38°	3.02	174.38°	3	175.08°	2.99	175.08°
3.5	125°	*	*	3.51	125.16°	3.5	125.16°	3.51	125.16°
4	75°	4	74.53°	4	75.94°	4	75.94°	3.99	74.89°
4.5	25°	4.48	25.31°	4.48	25.31°	4.52	25.31°	4.48	24.96°
5	25°	5.02	25.31°	4.97	25.31°	4.98	25.31°	4.98	25.31°
5.5	75°	5.42	75.94°	5.54	74.53°	5.5	75.23°	5.5	74.53°
6	125°	5.91	125.16°	6.04	125.16°	5.98	125.16°	*	*
6.5	175°	6.44	174.38°	6.44	174.38°	6.51	175.08°	6.51	175.08°
7	35°	6.87	35.16°	7.03	35.16°	7.01	35.16°	7.01	35.16°
7.5	85°	7.5	85.78°	7.5	85.78°	*	*	*	*
8	5°	8	5.63°	8	4.22°	8.01	4.92°	*	*

* Unable to register

TABLE II
SCALE FACTORS RECOVERED BY THE CORNER RESPONSE METHOD (CR) FOR THE STANDARD IMAGES

Scale	Clock	Camera-man	Van	Airfield
1	1	1	1	1
1.5	1.5174	1.5174	1.5092	1.4949
2	1.9785	2	2.0027	2
2.5	2.5108	2.5108	2.4838	2.4904
3	3.0348	3.0348	2.9898	2.9898
3.5	3.5316	3.5126	3.503	3.503
4	4	4	4.0054	3.9892
4.5	4.4816	4.5552	4.4696	4.5184
5	5.0216	5.0216	4.9676	4.9808
5.5	5.4172	5.4172	5.5356	5.4908
6	6.0696	6.0696	5.9796	5.9796
6.5	6.5476	6.5832	6.512	6.5132
7	7.0632	7.0252	7.006	7.006
7.5	7.5002	7.4968	7.446	7.446
8	8	8	8	*

* Unable to register

TABLE III
ROTATION FACTORS RECOVERED BY THE CORNER RESPONSE METHOD (CR) FOR THE STANDARD IMAGES

Angle	Clock	Camera-man	Van	Airfield
5°	5.625°	5.625°	5.625°	4.9219°
15°	14.0625°	14.0625°	15.4688°	14.7656°
25°	25.3125°	25.3125°	25.3125°	25.3125°
35°	33.75°	33.75°	35.1563°	35.1563°
45°	45°	45°	45°	45°
55°	56.25°	56.25°	54.8438°	54.8438°
65°	64.6875°	64.6875°	64.6875°	64.6875°
75°	75.9375°	75.9375°	75.9375°	75.2344°
85°	84.375°	84.375°	84.375°	85.0781°
95°	95.625°	95.625°	94.2188°	94.9219°
105°	104.0625°	106.875°	105.4688°	105.4688°
115°	115.3125°	115.3125°	115.3125°	115.3125°
125°	123.75°	126.5625°	125.1563°	125.1563°
135°	135°	135°	135°	135°
145°	146.25°	146.25°	144.8438°	144.8438°
155°	154.6875°	154.6875°	154.6875°	154.6875°
165°	165.9375°	165.9375°	164.5313°	165.2344°
175°	174.375°	174.375°	174.375°	175.0781°
180°	180°	180°	180°	180°

TABLE IV
SCALE FACTORS RECOVERED BY THE CORNER RESPONSE METHOD (CR)

Image	Input		Proposed Method	
	Scale	Angle	Scale	Angle
UBC	1.24	53°	1.245	52.03°
Ensimag	1.82	0.8°	1.839	0.7031°
Inira	2.4	44°	2.401	43.5937°
IniraModel	2.78	30°	2.779	30.2344°
South	3.06	18°	3.0636	17.5781°
Park	3.33	15°	3.3364	15.4688°
Boat	4	8°	4	8.4375°
Hirise	4.06	0°	4.0492	0°
Crane	4.5	25°	4.4096	24.6094°
Van	5	10°	4.9676	9.8438°
Resid	5.89	33.2°	5.8356	31.64°
Plant	5.28	0°	5.2844	0°
Clock	6.3	63°	6.304	63.2813°
Laptop	6.25	0°	6.2784	0°
CameraMan	7.5	50°	7.4968	50.625°
Vending	8.97	0°	8.8312	0°

TABLE V
COMPARISON OF MAXIMUM SCALE FACTOR FOR EACH IMAGE PAIR WITH CORNER RESPONSE METHOD (CR), FFT AND NGC

Image	FFT	NGC	Proposed
Crane	1.88	4.08	4.5
Hirise	1.69	3.47	4.06
Plant	1.76	4.21	5.28
Steps	1.77	4.5	3.07
Vending	1.88	6.07	8.97
Tractor	1.56	6.25	6.67
Painting	1.45	3.55	4.36

The Clock image shown in Figure 2(a) is used as the source image. It is scaled and rotated with 6.3 and 63° respectively, and then used as target image as shown in Figure 2(b). The registration result using the proposed approach is shown in Figure 2(c). Similar registration results are shown in Figures 3 - 7.

A. Registration for standard image

All the experiments were conducted on 256×256 images which are rotated by θ_0 and scaled by a as shown in Figures 2 - 3. All the images are preprocessed by Tukey window to decrease the rotation aliasing, and then in order to reduce the scale overlapping, the images are preprocessed by highpass filter. Different scale factors alone are applied on standard images in order to test the efficiency of Corner response method and their corresponding results are listed in Table II. From the table it can be observed that the corner response method works well for all the scale factors in all the images expect in the Airfield image with the scale 8. In Table III, we have shown different rotation parameter values on the test images and retrieved rotation values. Both the scale factor and rotation parameters were applied on the selected images and their registration results are tabulated in Table I. We have implemented the FFT based image registration scheme using corner response (CR) on nearly 800 image pairs and found that their image registration results are satisfactory.

B. Registration for real time image

The images of Figure 4 - 7 are used to test the estimation of real time images. We have performed the registration with different set of real time images and standard images and their corresponding results are tabulated in the Table IV. It can be observed that the proposed method yields robustness in scale, rotation and translation changes.

In Table V we have shown maximum scale factor for each image pair using our proposed method and Normalised gradient correlation (NGC) based method [16]. For Painting image NGC and FFT were able to recover scale up to 4.21 and 1.76 respectively, whereas our proposed method yields scale up to 5.28, from the table we can conclude that the performance of corner response method is comparable with NGC method.

Matlab R2010b running on 2.30GHz Intel core (TM) machine is used to perform all the experiments. Depending upon the image size and the richness of texture content in the image its computation time for registering an image pair varies. In our experiment, the target image of size 1024×1024 is registered in approximately 50 seconds.

VI. Conclusion

In this paper we have presented a fast image registration scheme based on FFT using corner response. The Corner response (CR) method is applied on a set of real image pairs to determine its respective geometric transformations. Experimental results illustrate the performance of the corner response method. It is able to recover scale factor up to 8. Our registration scheme works better than FFT method [14] and it is comparable with gradient based method [16].

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R. Kokila received her M.Sc and M.Phil from University of Madras during 2005 and 2006 respectively. She is pursing Ph.D at University of Madras. Area of scientific interest: digital image processing and artificial neural networks.

P. Thangavel received his M.Tech and Ph.D. from Indian Institute of Technology and Bharathidasan University respectively. He is currently working as Professor and Head of the Department of Computer Science, University of Madras. Area of scientific interest: algorithms and artificial systems.