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Automated Quality Inspection of PCB Assembly Using Image Processing

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Abstract**—**Quality inspection of PCB is a crucial stage in the assembly line as it provides an insight on whether the board works correctly or not. When the inspection is done manually, it is susceptible to human errors and is time consuming. The boards should thus be inspected at every stage of the assembly line and the process should be dynamic. This is achieved in this work through three crucial stages in the assembly line and by replacing the conventional manual inspection by using image processing to obtain a faster and more precise quality inspection. The solder paste inspection consists of pre-processing using blue plane conversion, comparing with the unsoldered board in blue color plane and post processing using overlay. The X-ray inspection basically consists of pre- processing the captured image by RGB to gray conversion with thresholding, comparing with the expected image and post processing using overlay to show the shorts that has occurred along the assembly. The conformal coating inspection uses conversion of the blue intensity emitted off the board under UV light to RGB scale. Each of the algorithms were tested using 48 actual in-production boards from Vinyas IT Pvt Ltd, a PCB assembly company based in Mysore. The processing time of the algorithms were found to be less than 2 seconds with an accuracy of 85.7%. The system was also found to be cost eff ective over existing systems available in the market.

Index Terms—Image processing, Solder paste, X-Ray, Conformal Coating, PCB, Automation

I. Introduction

Quality Inspection is a crucial stage in the production line of a product. It ensures functional and reliable products are being manufactured and provides insight on the technology that the manufacturer relies upon. When it comes to the Printed Circuit Board industry, quality control has major impact over cost, time, precision and reliability of production. Various stages of the production line needs to be quality controlled so that the whole process becomes error free and optimum precision is observed. Manual inspection of PCB's is laborious, time consuming and imprecise as it is susceptible to human error. This paper proposes the idea of using Image Processing techniques to automate the quality control of Printed Circuit Boards on a production line. The techniques presented can be adopted for a wide range of PCB's, and also for different manufacturing processes and applications. The various stages of the production line thus need to be quality controlled.

Printed Circuit Board manufacturers are moving towards more and more reliable, easy to use, cost effective and faster methods of production. With electronic components getting smaller by the day, the demand for a compact, robust and affordable machinery is on the rise. Industries must increase the production of the required boards and the produced boards must not be susceptible to errors. Thus, a slow and fallible quality control becomes a hindrance. Manual inspection and testing of defense grade boards are tedious and time consuming. Troubleshooting the board can take a couple of days.

The recent philosophy in production is that quality control is a non-outcome based process. Which means QC on its own does not contribute to production, but rather consumes time, labor and cost to verify the defects produced due to faulty upstream processes in the production line.

These issues are hereby addressed by the introduced Automated inspection system. This system is not placed at the periphery of the production line, but at the beginning and in between crucial stages to ensure a more reliable, cost effective and faster inspection. Automated inspection is performed by the computer algorithms, eliminating painstaking manual inspection which is prone to errors.

II. Literature Review

Yazidi, Khaoul and Darmoul (2018) [1] propose a new method of defect detection. They design and develop a distributed ontology-based quality control system that enables intelligent products to detect defects autonomously. A case study is conducted in a printed circuit board (PCB) assembly industry to demonstrate the feasibility of the suggested approach. They particularly show that ontologies contribute to the transformation of raw data to useful information for improved reliability and realization of distributed and autonomous quality control capabilities. Their approach is ideal and not algorithm based.

Shuqiang Huang, Jielin Zeng, Hongchun Zhou, Zhusong Liu and Yuyu Zhou (2017) [2] propose a method of using magnetic field to determine the exact location of solder shorts in the PCB. The method proposed in very complex and requires a highly precise magnetic field detector.

Jianjie Ma (2017) [3] used the referential approach. He acquired the initial standard image and updated it during the detection process. A suitable threshold was obtained by the histogram of the difference image to distinguish potential defect regions. The boundary lengths of the potential defect regions were used to identify the real defect. Then the improved region growing method was used to get the complete defect region which makes the defect recognition easier. Finally, he recognized each defect by calculating the changing times of the peripheral boundary pixels' gray scale value. Jianjic Ma's approach of finding the boundary pixels might not always be suitable. Blurry images or small specks of discontinuities in the image will give erroneous results.

Mukesh Kumar, Niraj Kumar Singh, Manjesh Kumar, Ajay kumar Vishwakarma (2015) [4] presents an algorithm mainly having two parts, one is image enhancement and other is standard template formation. Image enhancement includes color plane extraction, LUT Transformation, Thresholding, Filtering, and Advance morphology, while Particle analysis is used for standard template generation. Particle analysis consists of various processing operations and analysis functions that produce some information about the particles in an image. Standard template can be used for referential matching of automatic defect detection. Lastly the performance meter is used which gives the response time taken during execution of different steps. The execution time taken of the proposed algorithm is 140 ms. The image enhancement algorithms being used are time consuming and are not necessary for detecting defects. Simple methods and faster algorithms can be efficiently used.

Szu-Hao Huang, Ying-Cheng Pan (2015) [5] review various optical inspection approaches in the semiconductor industry and categorize the previous literatures by the inspection algorithm and inspected products. The vision-based algorithms that have been adopted in the visual inspection systems include projection methods, filtering-based approaches, learning-based approaches, and hybrid methods. Their summary is precise and contains lot of valuable information.

Vedang Chauhan, Brian Surgenor (2015) [6] put forth three new methods to apply in the assembly machines which are based on machine vision.

1. Gaussian Mixture Models (GMMs) with blob analysis
2. Optical flow
3. Running average

Amongst the three new methods, the running average method is experimentally proved to be the best in terms of having the lowest processing time per frame and the fastest response time.

Aghamohammadi A., Ang M.C., Prabuwono A.S., Mogharrebi M., Ng K.W(2013) [7] propose a novel automated visual inspection method for PCB. The proposed method uses a sequence of image processing techniques inspired by the theory of inventive problem solving (TRIZ) with Affine-SIFT image matching techniques to enhance the component placement inspection. Only analytic discussions are presented in this paper to support the potential of the proposed method.

N K Khalid, Z Ibrahim (2008) [8] concentrate their efforts on a different aspect of defect detection in the PCB manufacturing industry. PCB defects detection is necessary for verification of the characteristics of PCB to make sure it is in conformity with the design specifications. However, besides the need to detect the defects, it is also essential to classify these defects so that the source of these defects can be identified. Unfortunately, this area has been neglected and not been given enough attention. Their study proposes an algorithm to group the defects found on bare PCB. Using a synthetically generated PCB image, the algorithm is able to group 14 commonly known PCB defects into five groups.

The proposed algorithm includes several image processing operations such as image subtraction, image adding, logical XOR and NOT, and flood fill operator. Their study emphasizes defect categorization which is not necessary for small and medium scale industries.

Shih-chiech Lin, Chih-hisen Shou (2007) [9] propose a two-stages inspection process. In the first stage, the horizontal and vertical integral projections of the component electrode are obtained after segmentation in the red sub image, based on the projections, the location of component is identified by the sliding location window algorithm, then, the defects such as missing component, wrong component, shift and rotation are detected. In the second stage, the three color features are extracted from the component body and the Bayes classifier is used to inspect another wrong component class. The proposed inspection system is time consuming and unnecessarily complex.

Loh, Horng-Hai Lu & Ming-Sing (1999) [10] present a computer vision system using structured lighting, which provides them with an efficient solution for solder joint inspection. Their system uses a novel structured-lighting inspection technology to overcome some difficulties that traditional computer vision systems often experience. They developed a slant map surface shape estimation technique for the solder joint. From this technique, a solder joint can be determined to be a good (concave), bad (convex), bridged solder joint, or solder joint with surplus solder, or lacking solder. This method can be improvised by using the laser method.

M. Moganti, Fikret Ercala, Cihan H.Daglib, Shou Tsunekawac (1995) [11] summarizes the various technologies which are currently being used for QC in PCB manufacturing. Majorly there are five technologies used

1. Automatic visual/optical inspection
2. X-ray imaging
3. Scanned-beam laminography
4. Ultrasonic imaging
5. Thermal imaging

In their survey, algorithms and techniques for the automated inspection of printed circuit boards are examined. A classification tree for these algorithms is presented and the algorithms are grouped according to this classification. This survey concentrates mainly on image analysis and fault detection strategies; these also include state-of-the-art techniques. This has helped us in implementing our algorithms for our problem statement.

Roland T Chin, Charles A Harlow (1982) [12] present a paper which surveys publications, reports, and articles dealing with automated visual inspection for industry. Their summary paper provides links to other articles and publications where Visual Inspection of PCBs has been explained in detail.

III. Methodology

This section deals with the techniques used to implement automated defect detection in PCB assembly line using image processing algorithms. Mainly, three points in the PCB assembly line are chosen where Quality Assessment is very crucial. Three specific image processing algorithms are developed as shown in figure 1 which are discussed in detail further.

Image Acquisition is the first step where cameras are used to capture high resolution images of the board. In case of X-ray, images are downloaded from the X-ray machine. In case of UV light images, the images are captured under UV light set-up.

The second step is pre-processing where the acquired images are processed for enhanced contrast and denoising is done. This step is done in the camera API itself. The generated images are ready for further processing.

In this step, feature extraction is performed. The required features such as coordinates of pads or areas of required intensity are identified. Then problem specific algorithms are applied to detect the defects in the board.

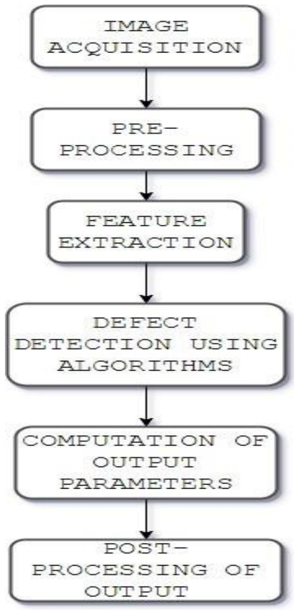

Fig.1. The basic process flow of the algorithm

Output parameters indicate the accuracy or quantize the defects using numbers and overlaid images. Finally, post-processing is done to provide a final image easy for humans to see and diagnose the issue. The technician would then use the overlain images to make the necessary corrections to the PCB.

3.1. Solder Paste Area

The bare PCB first undergoes screen printing where a paste of solder and flux is applied on the board through a stencil. All the pads to be soldered are covered by this paste. An image of the bare board is captured to calculate the total area of the solder-able pads as shown in figure 2.

After screen printing, an image is captured to identify the pads soldered by comparing it with the pre-captured image. The method used for this is comparison in the blue plane of all the color images, since pads without solder paste have negligible blue color component, while solder paste has significant blue color component.

Consider Y(:,;,:) as the image of the board before the solder paste in applied. X(:,:,:) as the image of the board after the solder paste is applied. X(:,:,3) and Y(:,:,3) corresponds to the blue planes of the two images.

The blue planes are subtracted and saved in the blue plane of a resultant image keeping the other two planes as 0, resulting in

$$B(:,:,3)=(:,:3)-Y(:,:3) \quad (1)$$

$$B(:,:,1) = 0 \quad (2)$$

$$B(:,:,2) = 0 \quad (3)$$

Where, B(:,:,1) and B(:,:,2) corresponds to the red and green plane of the resultant image.

Now B represents the area on the board, where solder paste is applied.

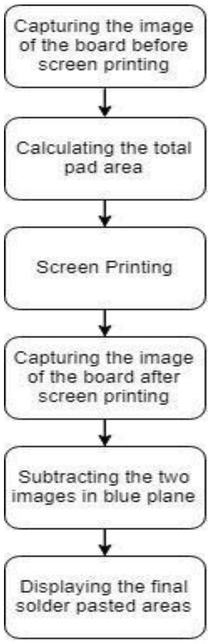

Fig.2. Flow diagram for Solder paste area recognition

3.2. X - Ray Inspection of BGA Pins

X-ray images from the scanning machine are acquired and images of solder from different layers are separated based on their intensity values. Then each image is processed and compared with the manufacturer specified layout to find defects and locate them.

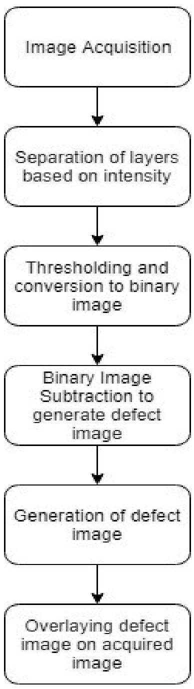

Fig.3. X-Ray inspection flow diagram

The technique used is to threshold the manufacturer's recommended solder pattern and convert it to a binary image. The acquired X-ray image is thresholded in a similar way to create a binary image. The two binary images are compared to generate an image with defects only. This defect image is type-casted and placed in the red plane of the acquired image. Hence defects appear as red overlay on the X-ray image as discussed in Figure 3.

Consider X as the x-ray image of the PCB currently being inspected. R corresponds to the master x-ray image, which is the image of a board, which is perfectly soldered.

First the images are resized to have the same dimensions.

Next the master x-ray image R is thresholded and converted to a Black-White Gray image with each pixel value being either 0 or 255 only.

If T is the threshold,

$$\text{If } X(a,b) < T, \quad \text{then } X(a,b) = 0 \tag{4}$$

$$\text{If } X(a,b) > T, \quad \text{then } X(a,b) = 255 \tag{5}$$

Let S correspond to the matrix formed by subtracting the thresholded Gray converted X and R images.

$$S = New(R) - New(X) \tag{6}$$

This matrix is used to create a red overlay on X where unnecessary shorts were formed, thus indicating the error points.

$$out(:,:,1)=X(:,:,1)+S \tag{7}$$

$$out(:,:,2)=X(:,:,2)-0.5*S \tag{8}$$

$$out(:,:,3)=X(:,:,3)-0.5*S \tag{9}$$

Here, out corresponds to the output displayed image.

3.3. Conformal Coating Uniformity Inspection

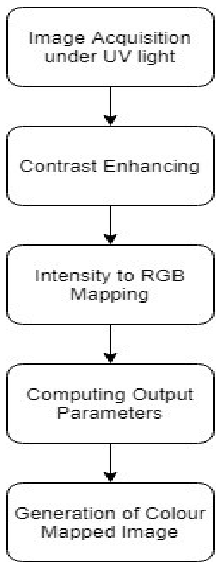

Fig.4. Conformal inspection flow diagram

Images of coated PCB's are taken under UV light and processed to enhance contrast as shown in Figure 4. Then a mapping is applied to convert variations in intensity to variation in color. Standard normal distribution is used to map intensity to color. Output parameters like average coating thickness can be calculated after calibration with the required UV illumination. The final colormap is displayed on screen indicating all areas of coating.

Consider U as the blue plane of the captured image of the PCB after conformal coating under UV light saved as a 1-D matrix. U(x,y) corresponds to a pixel in image U.

Let S be an assumed parameter between 0 and 255. (Our tests gave the best result for S = 75)

Color mapping was done using exponential relations to achieve better accuracy.

$$O(i,j,1) = 255*e^{-((U(i,j)-0)/S)^2} \quad (10)$$

$$O(i,j,2) = 255*e^{-((U(i,j)-127)/S)^2} \quad (11)$$

$$O(i,j,3) = 255*e^{-((U(i,j)-255)/S)^2} \quad (12)$$

IV. Experimental Results

4.1 Solder Paste Area

For the solder flux check, the algorithm can check how much of the board is pasted with solder flux and if an ideal image of board is uploaded to the system, it can correctly identify if all parts of the board is covered as expected. The main difference over existing method is that, one will be able to verify each board, rather than one in a few.

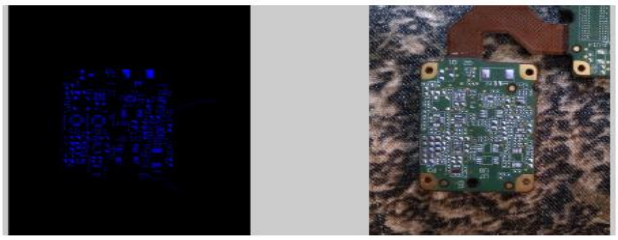

Fig.5. Solder Paste Area algorithm results

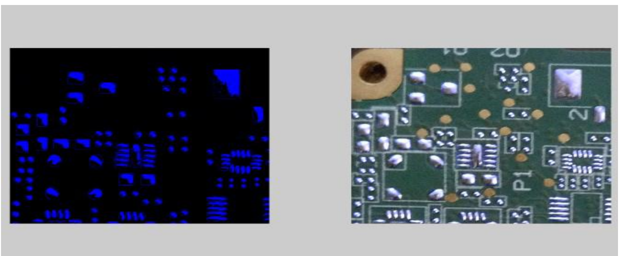

Fig.6. Solder Paste Area algorithm results

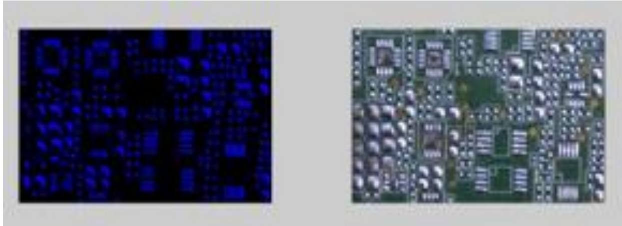

Fig.7. Solder Paste Area algorithm results

In the Figures 5-7, the first image shows the areas on the board where the solder paste is applied, achieved by image subtraction of solder pasted and non-solder pasted board and mapping it to blue plane. The second image shows the soldered area being overlaid on the soldered board.

4.2 X - Ray Inspection of BGA Pins

For the X ray check, the algorithm can check whether the BGA components are correctly soldered in one shot much quicker than a person checking it ball after ball. Again here, each board can be checked instead of one in a few. The company can upload different ball array images and still utilize the same system, even for new components. All that the product needs is one correctly checked image and then, the product will take images of the boards, along the assembly line, in very less time and more accurately than manual checking.

In the Figures 8-10, the first image is the Master image, which corresponds to the ideal image expected under X-Ray made into only Black-White image. The second image is the X-Ray image of the board being checked. The Red areas indicated in figures 8 and 10 are the areas on the board which have an extra solder junction, which makes the board unusable.

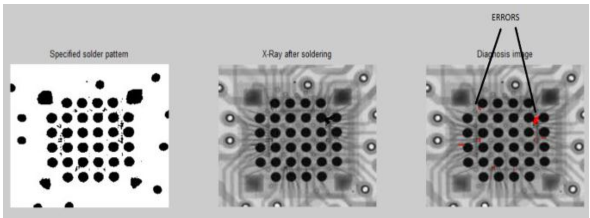

Fig.8. X-Ray inspection algorithm results

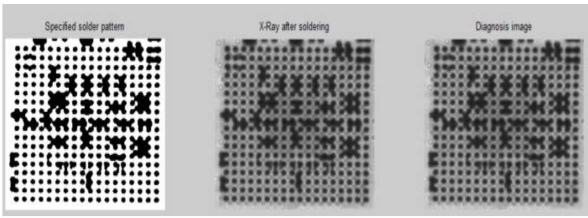

Fig.9. X-Ray inspection algorithm results

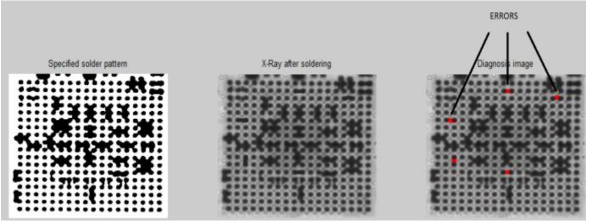

Fig.10. X-Ray inspection algorithm results

4.3 Conformal Coating Uniformity Inspection

In the conformal coating checking, the manual labor can check the uniformity of the coating applied on the board and correct them and verify the uniformity, thus improving the quality of the protection. Also, one main advantage is that, the algorithm doesn't require any minimum requirements and hence, quality of assembly can be maintained in all boards irrespective of the quantity being manufactured.

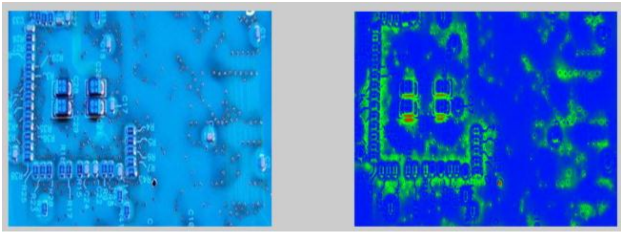

Fig.11. Conformal inspection algorithm results

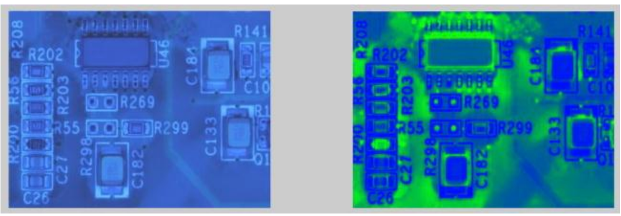

Fig.12. Conformal inspection algorithm results

Fig.13. Conformal inspection algorithm results

In the Figures 11-13, the first image is the picture of the conformal coated board under a UV source. The Red areas indicate the less coated and non-conformal coated areas which need more coating. The Green areas indicate areas with average and below averagely coated areas. The Blue areas indicate the areas with above average and very well coated areas.

4.4 Confusion Matrix Results

The accuracy and other parameters of the work was tested using the confusion matrix. 48 test samples were used to check the parameters. The test samples were actual in-production boards that were available at multiple points of production from Vinyas IT Pvt Ltd, a PCB assembly company based in Mysore. The test sample data was then put onto the Confusion Matrix table, shown in Table 1 and the evaluated parameters are shown in Table 2. The confusion matrix was used to find the parameters of all three areas together. Table 3 indicates the novelty of this work wherein this work proposes the application of simple image processing concepts for quality inspection of PCB and the rest of the approaches uses more complex concepts.

Table 1. Confusion Matrix

	True Positive	True Negative
Predicted Positive	21	3
Predicted Negative	4	20

True Positive (TP): Correctly predicting a label (we predicted “yes”, and it’s “yes”),

True Negative (TN): Correctly predicting the other label (we predicted “no”, and it’s “no”),

False Positive (FP): Falsely Predicting a label (we predicted “yes”, but it's “no”),

False Negative (FN): Missing and incoming label (we predicted “no”, but it’s “yes”).

Positives (P): the total number of cases we expected positive results.

Negatives (N): the total number of cases we expected negative results.

Using the values in the confusion matrix, different parameters were calculated.

Table 2. Performance Evaluation Of The Proposed Method

Measure	**Value**	**Derivations**
Sensitivity	84%	TPR = TP/(TP+FN)
Specificity	87%	SPC = TN/(FP+TN)
Precision	87.5%	PPV = TP/(TP+FP)
Negative Predictive Value	83.3%	NPV = TN/(TN+FN)
False Positive Value	13%	FPR = FP/(FP+TN)
False Discovery Rate	12.5%	FDR = FP/(FP+TP)
False Negative Rate	16%	FNR = FN/(FN+TN)
Accuracy	85.7%	ACC = (TP+TN)/(P+N)

Table 3. Comparison Of Methodologies

Algorithm	**Approach**
[2]	Magnetic field
[6]	Machine vision based on Gaussian Mixture Models (GMMs) with blob analysis or Optical flow or Running average
[7]	Image processing based on Affine-SIFT and TRIZ Techniques
Proposed	Image processing based on intensity matching, image subtraction and color mapping

V. Conclusion

This work was done on for **Vinyas Innovative Technologies Pvt. Ltd.** The company works in the field of automatic assembly of Printed Circuit Boards. The company wanted to automate the Quality Inspection and Assurance process which was mainly being done manually. Digital Cameras were used to capture images of the PCBs at various points in the assembly line wherever Quality checks are imminent; the captured images are processed using custom Image Processing algorithms; Defects and anomalies are detected and displayed on a new overlay image.

The work was found to be very useful for the automation of manual labor based PCB assembly line at a much cheaper cost than available systems and it was found to be 85.7% accurate based on the test results. Few of the boards tested were defense grade boards, so the accuracy was key.

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Authors' Profiles

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In 2007, he joined the Department of Electronics and Communication Engineering as a Lecturer in JVIT, Bidadi, Bangalore. In 2010, he joined the Department of Electronics and Communication Engineering as a Assistant Professor in BGS Institute of Technology, BG Nagar, Mandya. In 2017, he joined the Department of Electronics and Communication Engineering as a Associate Professor in PES College of Engineering Mandya. His current research interests include image processing, video processing, video shot detection etc. Dr Punith Kumar M B is a Life Member of the Indian Society for Technical Education (ISTE) and Associate Member of the Institution of Engineers (AMIE), Member of IEEE. He was the Judge, Chairperson and Review member for the National and International Conference.

Dr. Shreekanth. T completed his Bachelor of Engineering in Electronics and Communication from PES College of Engineering, Mandya, affiliated to Visvesvaraya Technological University, Belgaum, Karnataka, and obtained his master's degree in the area of BioMedical Signal Processing from, Sri Jayachamarajendra College of Engineering Mysore affiliated to Visvesvaraya Technological University, Belgaum, Karnataka. He completed his PhD in the area of Image and Speech signal processing from the University of Mysore, Mysore. His areas of interest include Digital Image Processing and Speech Signal Processing. He has to his credit more than 20 conference and Journal papers both at national and international level. He is worked as an Assistant Professor in the Department of Electronics and Communication at Sri Jayachamarajendra College of Engineering, Mysore, Karnataka, India.

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