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Comparative Study of Different Intensity Hue Saturation based Image Fusion Techniques in Remote Sensing

[1]Jinju Joy, [2]Santhi N, [3]Sanil J, [4]Ramar K

[1]Department of Electronics and Communication Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Kanyakumari District, Thuckalay, Tamil Nadu, India.

[2]Department of Electronics and Communication Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Kanyakumari District, Thuckalay, Tamil Nadu, India.

[3]Department of Electronics and Communication Engineering, Sarabhai Institute of Science and Technology, Vellanad, Trivandrum, Kerala, India.

[4]Department of Computer Science and Engineering, Muthayammal Engineering College (Autonomous), Rasipuram, Namakkal District, Tamil Nadu, India.

E-mail: [1]jinjujoy1@gmail.com, [2]santhiram@yahoo.com, [3]saniljayamohan@gmail.com, [4]kramar.einstein@gmail.com.

ABSTRACT

Remote Sensing is the process of gathering information about a particular area or an object from a distance usually from an aircraft or satellites. There are two types of sensors that are popular among remote sensing (RS) applications, one capable of providing images having good spatial resolution known as the Panchromatic Image (PAN) and another with a good spectral resolution, known as the Multispectral image (MS). Even though spatial information of the PAN image is relatively high, the associated spectral information is less. Similarly, for the MS image, the spectral information is more while lacking spatial information. This accounts for the need for a technique known as image fusion. Combining the information of an object or an area obtained from different sensors to produce a single fused image is the main concept behind image fusion. This paper is written to study the different image fusion techniques based on Intensity Hue Saturation (IHS) and to have a comparative study of these methods. IHS based image fusion techniques are considered in this paper as it is the simplest and most common image fusion technique among different remote sensing applications.

Keywords: *Image Fusion, remote sensing, intensity-hue-saturation, spatial domain.*

1. INTRODUCTION

Remote sensing (RS) is the field of science in which information about an object or a particular area is obtained from a distance. This information is provided by sensors placed either at an aircraft or a satellite. The main advantage of remote sensing is that it is possible to get information about the object or area without having a physical presence in the scene. This technique becomes extremely useful when the object or area is not hostile to humans and the data is gathered by utilizing the reflections from the region of interest. The sensors that detect this information can be either passive or active. Passive sensors are those which detect the energy emitted or reflected by the object or area, i.e. the reflected sunlight or thermal energy. Active sensors use artificial radiation to gather information about the object or area.

In remote sensing, images can be characterized into two types, Panchromatic image (PAN) and Multispectral image (MS). Both images have their advantages and disadvantages. Panchromatic images are usually single-band images that are represented in greyscale having high spatial resolution while the multispectral images (MS) are multi-band images having high spectral information. Spectral resolution can be thought of as the width of the electromagnetic spectrum which the sensor can sense effectively. These two images have complementary information. As both images have relevant information that is useful in remote sensing applications, it would be advantageous if both pieces of information are available together. This requirement marked the beginning of the concept known as image fusion [1],[2].

Image fusion is an image processing technique in which two or more images of the same scene or object or a particular area probably from different sensors are combined to form a single image incorporating pieces of information from both images. For image fusion to be effective, there are two requirements. Firstly, the image fusion technique must identify the relevant information from both the images accurately and incorporate them into the fused image without losing any relevant information. Secondly, the image fusion process should not produce artifacts in the fused image. Image fusion is executed to enhance the information available in the image so that we get a better insight into the details. Determining the quality of the fused image is another important milestone in image fusion. Several performance metrics [3]–[12] are defined which are used to check the quality of the fused image. These parameters give a vivid knowledge about how good and effective a particular image fusion technique is.

Based on the domain of operation image fusion techniques can be divided into two categories spatial domain and spectral domain image fusions. In the spatial domain method, fusion is done with pixel values while in the case of spectral-domain fusion techniques, the fusion is done by altering the frequency component of the image. Both methods have their own merits and demerits. Even though spatial domain methods are fairly

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easy to operate and provide good image enhancement, they produce something known as the spectral distortion. This spectral distortion can be avoided using spectral-domain image fusion techniques. In the case of spectral domain-based technique, the Fourier transform of the two images is calculated and the fusion process is done on the Fourier coefficients. Finally, inverse Fourier transform operations are carried to obtain the fused image.

The problem of spectral distortion can be addressed in many ways including spectral-domain image fusion techniques and several improved fused techniques based on the spatial domain. These techniques are found to be much better than conventional spatial domain-based image fusion techniques.

Many fusion techniques can be effectively used in the case of remote sensing applications, in both spatial and spectral domain image fusion methods. The most common and popular spatial domain image fusion technique is based on Intensity Hue Saturation (IHS). Being a common and simplest method of all, IHS and its various types of image fusion techniques that are generally used in remote sensing applications will be studied in this paper. The paper will enable the reader to understand the various features of the different types of image fusion techniques based on Intensity Hue Saturation.

2. IMAGE FUSION ALGORITHMS

In remote sensing applications, two types of resolution are of utmost importance, one belongs to the spatial quality known as spatial resolution, and other deals with spectral quality, spectral resolution. The spatial resolution shows how much finer details of the earth is detectable while the spectral resolution indicates the different ground covers. Most of the modern satellites are capable of producing images of two

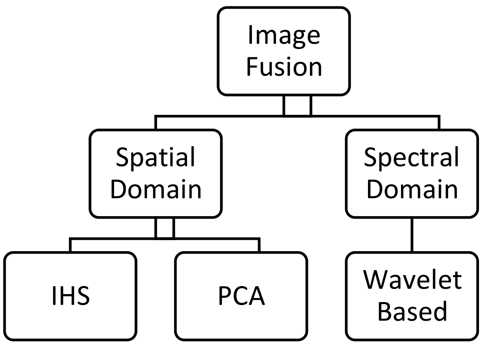

Figure.1. Basic spatial and spectral domain based image fusion techniques.

different quality, panchromatic image (PAN) and multispectral image (MS). A high spatial resolution and low spectral resolution are the characteristics of a PAN image while MS images have high spectral resolution and low spatial resolution. Many applications in remote sensing require images having better spectral and spatial resolution which are not readily available with conventional sensors.

This is the motivation behind the technique of image fusion, where two or more complimentary quality images are combined to incorporate all the relevant information at the same time without producing any artifacts [13]. As mentioned in the introduction section, image fusion methods are basically of two types. Spatial domain methods [14] done at the pixel level and spectral-domain methods done at the frequency level. The main features of Spatial and Spectral domain image fusion technique are given Table I.

Some of the important spatial and spectral image fusion technique which is commonly used in the remote sensing application are discussed in these papers [14], [15]. Figure 1. shows the basic classification of image fusion techniques. In spatial domain image fusion techniques, IHS & PCA [16] are most commonly used while in the case of spectral-domain methods wavelet transform based are popular. Spatial Frequency Discrete Wavelet Transform (SFDWT) [17], [18] based image fusion technique is the most recent spectral domain technique which yields excellent fusion result.

IHS based image fusion technique is one of the oldest and most popular image fusion techniques in remote sensing as it is simple, fast, and easy to implement. In the last few decades, there are various types of IHS based image fusion techniques that have been developed and implement in remote sensing. Figure 2. shows the various types of IHS based image fusion techniques. As mentioned earlier the main disadvantage of the spatial domain image fusion technique is that it has a poor spectral resolution. To improve the performance of IHS based image fusion algorithm different versions of techniques have been developed which will be reviewed in this paper.

TABLE I. COMPARISON OF FEATURES RELATED TO SPATIAL DOMAIN AND SPECTRAL DOMAIN-BASED IMAGE FUSION TECHNIQUES.

Technique	Features
Spatial Domain Technique	1. Pixel-Level Image Fusion. 2. Simple Method 3. Good Spatial Resolution. 4. Suffers from spectral distortion. 5. Good visual interpretation
Spectral Domain Technique	1. Pixel values are first transformed into frequency domain using DCT, DFT, any wavelet or frequency based image fusion methods 2. Based on multiresolution analysis. 3. Poor spatial resolution 4. No spectral distortion

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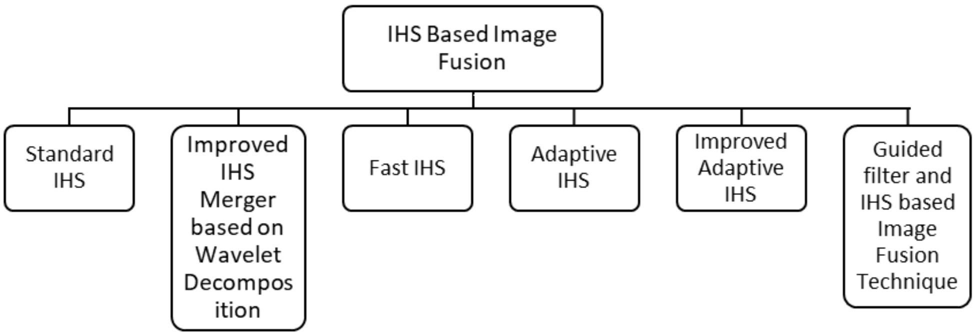

Figure.2. Different types of IHS based image fusion techniques.

3. INTENSITY HUE SATURATION BASED IMAGE FUSION TECHNIQUE

3.1 Standard Intensity Hue Saturation Image Fusion Technique

It is one of the most commonly used image fusion technique in remote sensing applications. Here color is represented by three independent parameters, Intensity, Hue, and Saturation. Hue is determined by the wavelength associated with the color, saturation represents the purity that depends upon the amount of white light that is mixed with hue, and intensity represents the brightness of the color. This method is commonly used in remote sensing applications where the MS image has three bands [19]. The basic concept of the IHS image fusion technique is that the MS image that is of lower resolution is first resampled to match the resolution of the PAN image into the IHS color space. Next, the intensity component of the MS image is replaced with the high-resolution PAN image which is histogram matched so to reduce the effect of illumination. Finally, the fused image is obtained by taking the inverse IHS transform to convert it back to RGB color space [20].

The main concept behind IHS transformation is a separation of spatial and spectral information. The spatial information is represented by the intensity component while spectral information is given by hue and saturation. As the intensity component of the MS image that represents the spatial information is replaced with the high spatial resolution PAN image, the spatial quality of the MS image is improved. The fused image has good spatial quality but the main disadvantage of the IHS method [21]-[22] is that it produces reasonable spectral distortion which is mainly due to the large deviation of intensity component between PAN image and MS image [23]. The major setback of the IHS image fusion method is that it can be applied only in the case of MS images having three bands.

3.2 Improved Intensity Hue Saturation Merger Based on Wavelet Decomposition [24]

The standard IHS image fusion technique is effective when the correlation of PAN image and intensity of MS image is very high. For the fused image to be of good quality, two conditions must be satisfied. Firstly, as in the standard IHS image fusion technique, the intensity component is evaluated as a linear combination of the different bands of MS image. A high correlation between the PAN image and intensity component is possible only if the bandwidth of the PAN image covers the entire bandwidth of the MS image. Secondly, both the PAN and MS images should be captured at the same time without any misregistration. If any of these two conditions are not satisfied, then the quality of the fused image will be affected. That is, when the intensity, hue, and saturation of MS image is found out, the spatial and spectral information will not be completely separated. Thus, the Hue and Saturation component of the MS image will contain some spatial details and in the same way, the intensity component will contain some spectral details. Thus, the fused image will contain more spatial information and spectral information than which would have been present if it had been collected at the resolution of the PAN image. Thus, instead of completely replacing the intensity component with the PAN image as in the case of standard IHS image fusion technique, only the spatial details which are missing in the MS image is introduced. This is the basic idea behind Improved Intensity Hue Saturation Merger [24]. In this method instead of simply replacing the intensity component of the MS image with the PAN image, the details are combined using decimated or undecimated wavelet decomposition. One disadvantage of this method is that it can be applied only to three bands. Another problem that might occur is the Gamut problem [25] which can be avoided by color clipping resulting in color distortion and contrast reductions.

The algorithm of improved IHS merger based on wavelet decomposition [24] is given below,

1. Register both MS and PAN images and make the resolution of MS image same as that of the PAN image.
2. Find the intensity component of the MS image by taking the IHS transform.
3. Generate a histogram matched PAN image
4. Find the decimated or undecimated wavelet transform of both intensity and histogram matched PAN image.

5. The spatial information of the PAN image that is missing in the MS image is injected into the intensity component of the MS image by taking the inverse wavelet transform.

6. Finally, the spatial information is injected into the MS image by taking the inverse IHS transform to obtain the fused image.

3.3 FAST Intensity Hue Saturation Image Fusion Technique [26]

Even though the IHS image fusion technique can produce good spatial quality, it may introduce spectral distortion which is the main drawback of the IHS image fusion technique. This problem can be reduced by using an improved version of the IHS image fusion technique which is known as fast IHS fusion technique [26], fast in the sense that fused image can be obtained by a simple addition operation. In the IHS image fusion technique, the hue component is unchanged but the saturation component is altered which results in color distortion. In this case, the saturation value is inversely proportional to the intensity value i.e. the saturation value is expanded when the PAN value is less compared to its corresponding intensity value and the saturation value is compressed when the PAN value is large compared to intensity. The main idea of the fast intensity hue saturation image fusion technique is to make the difference between the PAN value and intensity value as small as possible [27] so that the saturation value will not be altered thereby reducing color distortion. The difference between the PAN value and the intensity value is lowered by including NIR band into the intensity component which in turn extends the fusion from three-band to four bands including the NIR band. As in this method, spectral distortion is reduced by adjusting the spectral content, which is done by introducing a NIR band. This technique is also known as a spectrally adjusted IHS (SAIHS) method [28]. This method can be effective in the case of IKONOS images, not for other satellite images.

In the case of IKONOS imaginary of buildings, roads and soil regions, the saturation fusion value is expanded and the fusion quality is not affected much. But in the case of green vegetated regions, the saturation values are compressed thereby introducing color distortion. This color distortion problem in the case of IKONOS imaginary can be reduced effectively using fast intensity hue saturation image fusion technique. This technique in addition to reducing color distortion has fast computational capabilities.

3.4 Adaptive Intensity Hue Saturation Image Fusion Technique [29]

Spectrally adjusted IHS image fusion technique significantly reduces the spectral distortion in the case of IKONOS images. But when it comes to other satellite images it is found to be less effective. Another version of the IHS image fusion technique that reduces spectral distortion is the Adaptive Intensity Hue Saturation image fusion technique [29]. In this method, the spectral distortion is reduced by obtaining an image adaptive coefficient. Also, in this method, the edges of the panchromatic image are extracted and it is combined with the multispectral image thereby increasing the spectral quality.

Spectral distortion will be minimum when the intensity value is as close as possible to the PAN values. Thus, in Adaptive IHS, the spectral distortion is minimized by representing the intensity value by an adaptive linear combination of the MS bands with the image adaptive coefficient calculated in such a way that it best approximates PAN and intensity values. The coefficients are found by minimizing a function [30] which can be solved using the gradient descent method. In this method the edges of panchromatic images are also detected using some edge detector like a Canny edge detector, exponential edge detector, etc. and it is transferred to the fused image. In the adaptive IHS image fusion technique, the advantages of both images adaptive coefficient method and edge adaptive method are combined which will result in both spatial and spectral quality.

3.5 Improved Adaptive Intensity Hue Saturation Image Fusion Technique [23]

Insensitivity to misregistration and aliasing are the major advantages of the Adaptive Intensity Hue Saturation (AIHS) image fusion technique. But it also suffers from spectral distortion. If the spectral distortion can be avoided, then AIHS is a good and practical image fusion technique. In image fusion method, the aim is to inject the spatial details into the low-resolution MS image, once it is extracted from the PAN image. The amount of spatial details from the PAN image injected into each band of the MS image is given by the weighting matrix or called the modulation coefficient, which is an important parameter that determines the performance of the image fusion technique. Too much of spatial information injected into the MS image can lead to spectral distortion due to redundant information and if the spatial information injected into the MS image is less, then the overall spatial resolution of the fused image will be less. In the case of the Adaptive intensity hue saturation image fusion technique, the edge details of the PAN image are also injected into the MS image, thus the weighting matrix known as the Pan induced weight is also a function of edge.

In most of the cases, the edges which are present in the PAN image may not be present in all the bands of MS image, so if the same amount of detail is injected into the different bands which are usually done in the case of AIHS method by PAN-induced weight, can introduce spectral distortion. This is the main drawback of the Adaptive Intensity Hue Saturation image fusion technique, as a result, the fused image will have a high level of sharpness. This problem is addressed in the case of Improved AIHS [23] method where instead of injecting the same amount of details into different MS bands using PAN-induced weight, MS-induced weight is used which will make sure that different levels of details are injected thereby reducing spectral distortion. MS-induced weight is introduced in such a way that the proportion of different pairs of MS images remains unchanged. It is found that the Improved AIHS method was able to perform much better than other weighting schemes.

TABLE II. COMPARISON OF FEATURES OF DIFFERENT VERSIONS OF INTENSITY HUE SATURATION BASED IMAGE FUSION TECHNIQUES

Sl No	Technique	Features
1	Standard Intensity Hue Saturation Image Fusion Technique	1. Popular technique in RS applications where the multispectral image has only three bands. 2. Intensity component of the MS image is replaced with PAN image which is histogram matched with MS image. 3. Fused image has good spatial resolution 4. Produces spectral distortion mainly due to lack of correlation between PAN image and intensity component of MS image.
2	Improved Intensity Hue Saturation Merger based on Wavelet Decomposition	1. Replacement of Intensity component of MS image with the PAN image is not done. 2. The missing spatial details of MS image is injected from that contained in the PAN image. 3. Injection of spatial details into the MS image is completed by taking decimated or undecimated wavelet decomposition. 4. It can be only applied to images with three bands usually RGB compositions. 5. Suffers from spectral distortion.
3	Fast Intensity Hue Saturation Image Fusion Technique	1. The main idea is to make the variation between panchromatic image value and intensity value as small as possible [28] so that the saturation value will not be altered thereby reducing color distortion. 2. The variation among PAN value and intensity value is lowered by including NIR band into the intensity component which in turn extend the fusion from three band to four bands including NIR band. 3. As in this method, the spectral distortion is reduced by adjusting the spectral content that is by introducing the NIR band. This technique is also known as spectrally adjusted IHS (SAIHS) method [29]. 4. This method can be effective in the case of IKONOS images not for other satellite images. 5. Fast computational capabilities.
4	Adaptive Intensity Hue Saturation Image Fusion Technique	1. Spectrally adjusted IHS image fusion technique significantly reduces the spectral distortion in the case of IKONOS images. But when it comes to other satellite images it is found to be less effective. 2. The spectral distortion is reduced by obtaining image adaptive coefficient. 3. The edges of the panchromatic image are extracted and is combined with the multispectral image using edge detector like Canny edge detector, exponential edge detector etc. 4. The intensity value is represented by an adaptive linear combination of the MS bands with the image adaptive coefficient calculated in such a way that it best approximates Pan and intensity values. 5. The coefficients are found by minimizing a function which can be solved using gradient descent method. 6. Insensitivity to misregistration and aliasing. 7. Suffers from spectral distortion and have a high level of sharpness as the same amount of details of PAN image are injected into the different bands using PAN-induced weight.
5	Improved Adaptive Intensity Hue Saturation Image Fusion Technique	1. The problem of high level of sharpness of AIHS is addressed in Improved AIHS method 2. Instead of injecting the same amount of details into different MS bands using Pan induced weight, MS induced weight is used which will make sure that different levels of details are injected thereby reducing spectral distortion. 3. MS induced weight is introduced in such a way that the proportion between different pairs of MS image remains unchanged. 4. Found to perform much better than other weighting schemes.
6	Guided Filter Intensity Hue Saturation image fusion technique.	1. Improved AIHS method results in images with too many edges. This drawback is solved in guided filter IHS method. 2. The high resolution panchromatic image is passed through a laplacian filter to produce a high pass Image. 3. High pass image and the initial weight is passed through the guided filter to get the redefined weight for the spatial detail injections. 4. A single weight is used for each multispectral bands. The weight with highest mean value is selected.

3.6 Guided Filter And Intensity Hue Saturation Based Image Fusion Technique [30]

The main drawback of adaptive IHS was that the weights induced by the edges of the panchromatic image sometimes become too large and it introduces color changes in the vegetation areas. Improved adaptive intensity hue saturation was developed to overcome this problem. One of the limitations of improved adaptive intensity hue saturation image fusion technique is that it might result in images with too many edges.

To overcome this problem in addition to the spectral distortion introduced by IAIHS, the guided filter is used to redefine the induced weights in the case of improved IHS method. In GFIHS [30] image fusion method guided filter is used to find a redefined weight. The high-resolution panchromatic image is passed through a Laplacian filter to produce a high pass image which along with the initial weight is passed through the guided filter to get the redefined weight for the spatial detail injections. Usage of different weights for each band of the multispectral image will improve the spectral quality but it adversely affects the spatial quality. So, in GFIHS, a single weight is used for each multispectral band. The weighting matrix of each band of a multispectral image is calculated and one with the highest mean value is used to insert the spatial details. In this method, the IHS transform is used to decompose the image into different components and the guided filter is used to find the redefined weights.

4. FEATURES OF DIFFERENT IHS BASED IMAGE FUSION TECHNIQUES

Various types of IHS based image fusion techniques commonly used in remote sensing applications have been discussed in section 3. The main purpose of this section to list out the key features of all the techniques and present it in a tabular form to enable the reader a comprehensive idea about the techniques. From Table II, the reader will be able to identify the key features of the various techniques and some of the highlighting features of the different versions of IHS based image fusion techniques are listed below. When it comes to different versions, the simplest and easiest techniques is the standard IHS technique. Among the different types the fastest technique is Fast IHS technique but the same cannot be applied to images from all the satellites. When it comes to IKONOS images Fast IHS and Adaptive Intensity Hue Saturation image fusion technique are found to be better than other techniques. Adaptive IHS technique is also found to be insensitive to misregistration and other aliasing effects. Improved IHS Merger based on wavelet decomposition can be considered as a hybrid image fusion technique in which fusion is done incorporating spatial and spectral domain concepts.

5. CONCLUSION

Spatial domain-based image fusion techniques have been used by scientists for many decades in solving remote sensing problems. Simplicity is considered as the key attribute behind its vast application. However, the formation of spectral distortion during fusion is one of the major limiting factors. With the advancement in technology and computational power, many new varieties of spatial domain techniques have developed which are found to be effective in solving spectral distortion problems. The various IHS based image fusion techniques and their features have been studied in this paper. From the study, it is clear that many methods are capable of reducing the spectral distortion and besides each technique has its own merits and demerits, and depending upon the applications the techniques should be selected for performing fusion.

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AUTHOR PROFILES

Mrs. Jinju Joy procured her M Tech degree in VLSI and Embedded Systems from Cochin University of Science and Technology, Cochin, in 2013.

She is currently working as Assistant Professor in the department of Electronics and Communication Engineering, Lourdes Matha College of Science and technology, Trivandrum, Kerala, India. Her innovate scientific analysis was published by IEEE in 2013. Statistical signal processing, estimation and image fusion are her research interests.

Dr. Santhi N received the Ph.D. degree from Dr. M.G.R. Educational and Research Institute University, Chennai, India. She has published many papers in journals and conferences. Her research interests are in Image Processing, Pattern Recognition, Image Retrieval and Soft Computing.

She is working as Associate Professor in the Department of Electronics and Communication Engineering, Noorul Islam Center for Higher Education, Kumaracoil, Tamil Nadu, India. She has been in the teaching and research field for more than 20 years.

Mr. Sanil J procured his M Tech degree in VLSI and Embedded Systems from Cochin University of Science and Technology, Cochin, in 2013 and doing PhD-Part Time.

He joined the Department of Electronics and Communication Engineering, Sarabhai Institute of Science and Technology, Vellanad, Trivandrum, India in 2010, where he is presently an Assistant Professor. He has published many innovate scientific papers in reputed International Journals and Conferences. Image Processing, Remote sensing, Statistical signal processing, detection, estimation, stochastic filtering, target tracking and Monte Carlo methods are his research interests. A university 6th rank for M Tech is his crowning achievement.

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Dr. K Ramar received the Ph.D degree in Computer Science and Engineering from Mononmaniam Sundarnar University, Thirunelveli, Tamil Nadu, India. He has published many Journals, conferences and guided many Ph.D scholars. His area of interest is distributed computing in Real time systems and Image Processing.

He is currently the Professor and Dean in the department of Computer Science and Engineering of Muthayammal Engineering College, Rasipuram, Namakkal, Tamil Nadu, India. He has been in the teaching and research field for more than 30 years.