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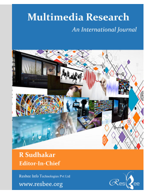

Study and Analysis of Various Pan-Sharpening Techniques: A Challenging Overview

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Abstract: Satellite sensors acquire massive data to exploit and address numerous human tasks. Due to the physical constraints, the usage of high spatial resolution multispectral (MS) images cannot be acquired by the unique devices. Hence, it is necessary to develop techniques by incorporating the images of MS and the panchromatic (PAN), also called Pan sharpening in remote sensing applications. Hence, this survey analyzes 30 research existing papers in Pan sharpening, which is based on various techniques, like neural network-based techniques, image fusion-based techniques, guided filter-based techniques, and optimization-based techniques. The analysis is based on the publication year of the research paper, research techniques employed, performance evaluation measures, and achievement of the research techniques. Also, the issues in the approaches are explained. Moreover, the future scope is to develop an efficient Pan sharpening technique based on the limitations recognized from the existing research Pan sharpening techniques.

Keywords: Multi-spectral images, Neural Network, Panchromatic image, Pansharpening, Remote sensing.

1. Introduction

Remote sensing technology has played a significant role in various applications. The satellite usually consists of two types of sensor imaging devices, namely PAN sensors and MS sensors. An MS image contains low spatial and high spectral resolution, whereas the PAN images contain low spectral and higher spatial resolution. To obtain the pan sharpening the PAN images and MS images are incorporated with low resolution, which has gained significant attraction in remote sensing fields [3] [26]. The goal of Pansharpening is to evaluate and restore the MS images in the high-resolution space with respect to two different inputs, such as PAN image with high resolution, and MS image with low resolution. The multi-resolution-enabled image fusion is not restricted to the image pairs of MS and the PAN. For instance, in hyper-sharpening, an image with high resolution is considered as the MS image, whereas the image with low resolution is considered as the hyper spectral image. Several algorithms and techniques are developed to solve this issue during the past three decades with the different technique categorizations or groupings [4] [27].

Recently, numerous researches focus to enhance the performance of Pansharpening tasks by maximizing overall layers in the neural networks. The most popular techniques can be partitioned into two various ways. The first group of techniques are called as Component Substitution (CS) techniques and are based on the linear spectral transformation. For instance, Intensity-Hue-Saturation (IHS), Gram-Schmidt orthogonalization (GS), and the Principal Component Analysis (PCA), are the common techniques based on the first group. In addition, the second group of techniques utilize the spatial frequency decomposition, which includes techniques such as high pass filtering (HPF) approaches, filtering in Fourier domain or Multi-Resolution Analysis (MRA)-enabled wavelet transform, boxcar filter in the signal domain, In addition, a third group of techniques are widely distributed in remote sensing community. These are the so-called model-driven optimization techniques concerning the minimization of model error residuals, such as Bayesian, unmixing or sparse representation (SR)-enabled techniques. In other words, these techniques are also called Variational Optimization (VO)-enabled methods. The two different pansharpening enhancement approaches, such as PAN image histogram matching [17], and addition of image configuration or image acquisition model into pan sharpening techniques have been widely used during the modern decade [4]

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Due to the physical constraints, the usage of high spatial resolution multispectral (MS) images cannot be acquired by the unique devices. Hence, it is necessary to develop techniques by incorporating the images of MS and the panchromatic (PAN), also called Pan sharpening in remote sensing applications. The major goal of this research is to analyze several existing Pan-sharpening techniques. The existing methods are categorized into Neural Network-based techniques, Image fusion-based techniques, Guided filter-based techniques, and Optimization-based techniques. The survey is conducted based on the deployed performance evaluation metrics, publication year, and so on. Moreover, the Spectral Angle Mapper (SAM) metric was reviewed for evaluating the performance of the Pansharpening. Therefore, it is considered as a motivation for the future plan for designing effectual Pansharpening techniques.

The structure of the survey paper is arranged as follows: the various existing Pan-sharpening techniques are reviewed in section 2, section 3 describes various research gaps and issues, the study of the techniques by considering the evaluation metrics, year of publication is explained in section 4, and finally, the conclusion of the paper is portrayed in section 5.

2. Literature Review

This section presents the different techniques, adopted in efficient Pansharpening. Accordingly, the research papers are analyzed, and the Pansharpening schemes practiced are classified into three different categories, Neural Network-based methods, Image fusion-based methods, Guided filter-based methods, and optimization-based methods. Figure 2.1 depicts the classification of the several techniques employed for Pansharpening.

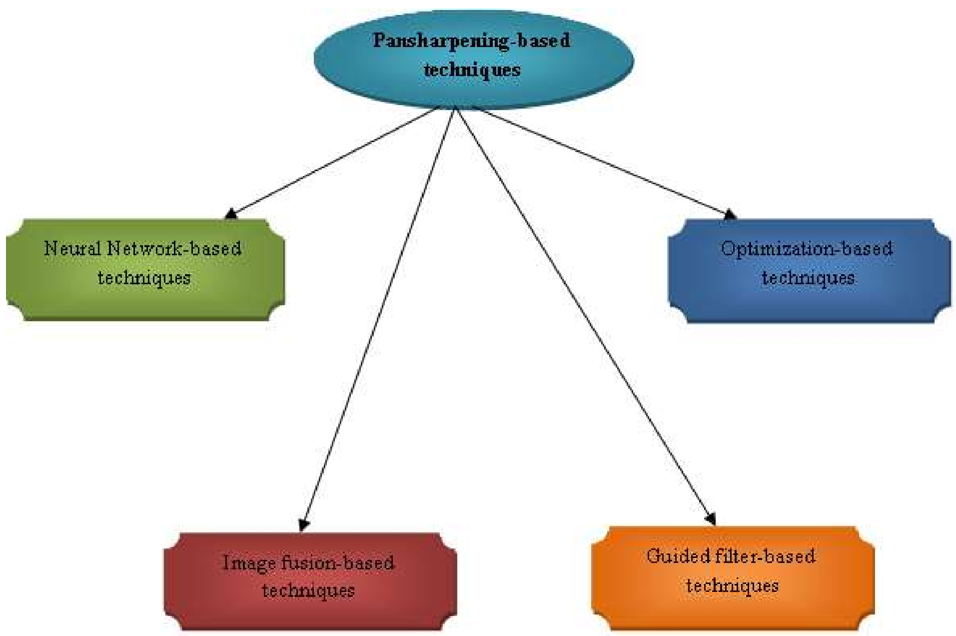

Fig.1. *Categorization of Pansharpening methods*

2.1 Neural Network-based Techniques

This section shows the various Neural Network-based techniques carried out for Pansharpening, which are explained below as follows, Liu Q., *et al.* [2] designed a Hybrid Attention scheme-based Residual Neural Network (HARNN) for pan-sharpening. Here, an encoder attention module was employed for the feature extraction phase in such a way that the MS and PAN images with spatial and spectral features were utilized effectively. In addition, the fusion attention module was employed for alleviating the spectral distortions, and then enhanced the fused image contour information. Finally, the tasks based on pansharpening were performed effectively.

Xu S., *et al.* [3] devised a deep convolutional sparse coding network for pan-sharpening. Here, the low-resolution MS images were partitioned into PAN images with respect to the related and the unrelated feature maps. In addition, the details from PAN images were incorporated along with the regularization terms of feature space. This technique achieved effective performance in processing the pan-sharpening tasks.

Wang W., *et al.* [7] designed a multi-scale deep residual network (MSDRN) for pan-sharpening the MS images. Here, multi-level network was employed for scaling the source images. In addition, residual learning was used for enhancing the feature extraction process, and the learning process. Moreover, this approach facilitated the network input to be completely transferred to the network output for preserving spatial and spectral information. Finally, this technique made the process of network training easier.

Vitale S and Scarpa G., [11] introduced a target-adaptive Convolutional Neural Network (CNN) for pan-sharpening with the enhanced capability at superior resolution. This approach incorporated the high and low resolution in such a way that the spatial properties were computed. In addition, this method was comprised of loss terms calculated at minimized and full resolutions in order to enforce cross-scale consistency.

He L., *et al.* [14] introduced a Hyper spectral pansharpening based on the spectrally predictive CNN (Hyper PNN) approach for hyper spectral pan-sharpening. This technique effectively reduced the spectral range among the PAN and MS images. This technique simultaneously resolved the continuous narrow bands. Moreover, this approach effectively enhanced the capability based on the spectral prediction in the pan-sharpening network. In addition, two improved pan-sharpening CNN models, such as HyperPNN1 and HyperPNN2 were employed for achieving effective spectral predictions in the pan-sharpening task.

Azarang A and Ghassemian H., [15] introduced a robust pan-sharpening technique using the MRA. In this approach, a lower resolution PAN image was generated with respect to the high-resolution versions. After that, the association among the high resolution and the lower resolution was applied for reconstructing the higher resolution MS images. In addition, the Deep Neural Network (DNN) was employed for identifying the relationship among the re-sampled version and the PAN image patches. Once the DNN training was performed, the lower resolution MS image was subjected to the trained network for generating MS image with efficient spatial details, and finally, images were fused to improve the pan-sharpening tasks.

Ehlers M., *et al.* [16] introduced a multi-sensor image fusion technique for Pan-sharpening. This technique effectively incorporated the PAN image with MS image in such a way that the superior-resolution multi-spectral images were obtained. In addition, spectral representations of the MS data were preserved. Finally, this technique achieved effective multi-sensor fusion by enhancing the spectral consistency

He L., *et al.* [18] devised a detail injection pan-sharpening framework, named (DiPAN) for the Pansharpening in an end-to-end way. This technique offered explicit physical interpretations by obtaining faster convergence results by enhancing the pan-sharpening quality. This technique effectively minimized the uncertainty in learning in such a way that this technique obtained enhanced computational efficiency. In addition, multi-resolution images were decomposed in such a way that the spatial representations were extracted and hybridized in a multiple scales.

Li Z and Cheng C., [23] designed a CNN-enabled pan-sharpening approach for incorporating the MS images and the PAN images. In this approach, the MS images were upgraded and then incorporated with PAN images for obtaining MS images with improved spatial resolution. In this technique, the non-linear fusion procedure was simulated by utilizing multiple linear filtering layers in order to learn the complex mapping association among the MS images and the PAN image. Finally, this approach achieved effective performance in various remote sensing areas.

2.2 Image Fusion-Based Techniques

The various research works based on image fusion-based approaches are explained below as follows: Palubinskas G., [4] introduced a knowledge-based image adjustment technique for improving the multi-resolution based pan-sharpening. Here, the adjustments were made for the PAN images such that the intensity of the image was computed as the weighted sum of MS bands. After that, the calculated weight was used for balancing the energy among the reflectance and the radiances of the sensors. Finally, this technique achieved effective performance by decreasing the computational complexities. Zhu XX and Bamler R [13] designed a sparse image Fusion algorithm for the image fusion. Here, the compressive sensing theory was employed, and then the sparse presentation of the MS image was explored in the dictionary pairs for enhancing super resolution capability. Furthermore, this approach achieved enhanced spectral and spatial resolution with the lowest spectral distortions.

Masi G., *et al.* [19] introduced a pan-sharpening technique, termed CNN for executing the process of pan-sharpening. In this approach, domain-specific knowledge was utilized for improving the performance in the remote sensing fields. Here, the radiometric indices were augmented, and then the features were tailored to resolve the super-resolution issue. In addition, the obtained non-linear indices were extracted effectively using CNN for minimizing the energy during the Pansharpening tasks. This technique achieved effective performance by minimizing the training complexities.

Khateri M and Ghassemian H [22] designed a self-learning approach for pan-sharpening low-resolution MS images. Here, numerous structures from the natural language were applied in a repetitive manner fat multiple scale. This technique utilized the high-resolution PAN image, and degraded version for reducing the dissimilarity among the intensity and high-resolution PAN images. Moreover, high resolution intensity element was calculated from the upsampled multi-spectral bands in such a way that the MS images with low and high resolution were fused, and hence the spatial and the spectral data of the source images were efficiently constructed for the pan-sharpening tasks.

2.3 Guided Filter-Based Techniques

This section elucidates the guided filter-bases techniques, which are described below, Li X., *et al.* [12] devised an efficient technique, named as guided filtering for pan-sharpening. This filtering technique was utilized for refining the blocking edges in the upscaled MS images in such a way that the extraction of high-frequency details from the PAN image was obtained. In addition, the higher spatial resolution PAN image was used for transferring the structures to the upscaled MS image, and smooth PAN image. Moreover, this method was performed in a band-by-band manner in such a way that the spectral relationship was computed between MS and PAN image.

Qi W*., et al.* [17] introduced a fusion scheme, named guided filtering and hyper spherical color transformation (HCT) for enhancing the process of pan-sharpening in the remote sensing fields. This technique utilized the guided filtering for transferring the PAN image structures to the MS image intensity in such a way that the block edges were refined. In addition, higher frequency information was obtained based on the guided filtered PAN image. This technique simultaneously sharpened the MS images by producing pan-sharpened results.

Gao Y., *et al.* [21] designed a scale-aware pan-sharpening technique for the pan-sharpening process. In this approach, the rolling guidance filter was utilized for partitioning the structural information, and then the partitioned information was injected based on the Gram-Schmidt transformation. This technique effectively improved the spatial resolution of MS images by computing quality indices in such a way that spectral information was preserved.

2.4 Optimization-Based Techniques

Wenqing Wang, *et al.* [28] implemented an optimization based adaptive CS fusion framework for better pan-Sharpening. Here, the particle-swarm-optimization algorithm (PSO) was used for measuring the radiometric similarity among Pan Image and low-scale intensity image. This method offered better results in fusion but some important indexes, like spectral angle mapper was not considered.

Muhammad Murtaza Khan, *et al*. [29] developed a Quality Without Reference (QNR) optimization based method for enhancing the pan-sharpened images quality. The simulated annealing (SA) algorithm was used for the optimization and it produced better quantitative results with low resolution images. However, this method suffered from spectral distortion.

Yingxia Chen and Guixu Zhang, [30] implemented pan-sharpening approach using evolutionary optimization and adaptive intensity-hue-saturation (IHS) transformation approach. Here, the evolutionary algorithm was used in the optimization of the control parameters, which supports the reconstruction of the synthesis image. However, this method was unable to circumvent local dissimilarities among the PAN and MS images.

Jamal Saeedi and Karim Faez [31] implemented multiobjective particle swarm optimization (MOPSO) for pan-sharpening the MS image. In this method, two types high resolution image was produced based on high radiometric quality and spatial similarity. The good spatial similarity was the major advantage of this method. Anyhow, local parametric estimation was needed to be improved.

Devi, *et al.* [32] developed a pan-sharpening model based on Lagrange Optimization and image fusion. This method enhanced the spectral consistency and offered better performance results than the existing methods. Anyhow, different kinds of input data affected the performance of this method.

2.5 Other Pan Sharpening Techniques

The various research works-based on the other Pansharpening techniques are elucidated as follows: Alcaras E., *et al.* [1] devised a Geographic information system (GIS) basic functions for the automatic Pansharpening. Here, the process of pan-sharpening was based on the raster utility and the open-source software. Here, a graphical modeler was employed for facilitating the pan-sharpening applications. Finally, the Map algebra operators were incorporated along with the scripts and procedures in order to perform the complicated tasks.

Smadi AA., *et al.* [5] developed a Kernel-based image filtering technique for obtaining the high-frequency information from PAN image. In this method, different kinds of side window-guided filters were utilized for improving the MS band from the PAN image. After that, these guided filters were used for adjusting the spatial data inconvenience. Finally, this approach achieved an effective image fusion process with enhanced computational effectiveness.

Lee J., *et al.* [6] developed a shift-invariant pan-sharpening with moving object alignment (SIPSA-Net) for pan-sharpening. Here, a feature alignment module was employed for incorporating multiple features with respect to the MS and PAN domains. In addition, the developed technique was optimized for aligning the colors from the MS images. Moreover, shift-invariant spectral loss was utilized to reduce the local misalignments, and finally an effective pan-sharpening performance was achieved.

Mankar R., *et al.* [8] introduced a Fourier Transform Infrared Technique (FTIR) for the multi-modal image sharpening. In this technique, curvelet-enabled multi-modal fusion approach was employed for fusing the spatial information in such a way that the spatial information from the dark-field images was fused into FTIR hyper spectral images. This technique was more appropriate for the biomedical images with curved discontinuities. Finally, this method achieved effective performance by enhancing the spatial-spectral quality.

Fu X., *et al.* [9] devised a variational pan-sharpening approach with local gradient constraints for pan-sharpening. In this technique, the spatial representations were used for enhancing the generalization ability. The convex optimization approach was employed for enhancing the performance efficiency in such a way that this method achieved effective performance in maximizing the spatial resolution of fused results.

Restaino R., *et al.* [10] introduced a Context-adaptive Pansharpening approach for improving the spectral diversity. Here, the binary partition tree segmentation algorithm was employed for evaluating the injection coefficients over partitioned image segments. In addition, two novel algorithms, named generalized Laplacian pyramid method and Gram-Schmidt orthogonalization procedure was applied in order to achieve an effective trade-off among the computational complexity and the accuracy.

Saxena, N. and Sharma, K.K., [20] devised a hybrid pan-sharpening technique based on the Hilbert vibration decomposition (HVD). In this technique, PAN, and the MS images were decomposed into numerous frequencies and the amplitude components in a decreasing energy order by utilizing the HVD. In addition, the amplitude of the first component with the maximum energy was applied for generating the pan-sharpened image. This technique effectively improved the spatial and spectral quality by utilizing the fusion-based schemes, thereby enhancing the process of pan-sharpening.

Yang Y., *et al.* [24] devised a pan-sharpening framework based on the multi-scale transform and the Matting Model (MM). Initially, this framework utilized the intensity element of the MS image for generating the spectral representations. After that, the multi-scale transform was utilized for fusing the upsampled components, and the PAN image for achieving a high-resolution fused image. In addition, the fusion-based rules were employed for fusing the high-frequency components, and low frequency components in the transformation domain. Finally, the MS image with the higher resolution is obtained effectively in the pan-sharpening fields.

Wang, P., *et al.* [25] developed a pan-sharpening algorithm, named as the Maximum a Posteriori Probability (MAP) approach for the remote sensing areas. This technique effectively generated the enhanced resolution image by applying the MAP approach to the original coarse image. In addition, a mapping operator was employed for transforming original high dimensional data to low dimensional data in the pan-sharpening process. Here, the PAN image and the original coarse image were fused for enhancing the classification accuracy, and computational efficiency.

The review on various existing pan-sharpening techniques is depicted in Table 1.

Table.1. *Review on various existing pan-sharpening techniques*

Author	Method	Merits	Demerits
		Neural Network-based techniques	
Liu Q., *et al.* [2]	HARNN	• Enhanced the contour information of the fused image. • The tasks based on pan-sharpening were performed effectively.	• Failed to explore the utilization and extraction of the multi-scale features
Xu S., *et al.* [3]	deep convolutional sparse coding network	• It achieved effective performance in processing the pan-sharpening tasks	• Failed to reduce the communication cost and overhead issues.
Wang W., *et al.* [7]	MSDRN	• This technique made the process of network training easier for preserving spatial and spectral information.	• Does not consider the MS and the hyper spectral image fusion approaches.
Vitale S and	target-adaptive CNN	• Used to compute spatial properties.	• The major challenge lies in utilizing suitable cropping mechanisms.

Scarpa G., [11]		• Enforce the cross-scale consistency	
He L., *et al.* [14]	Hyper PNN	• Reduce the spectral range among the PAN and MS images. • Achieve effective spectral predictions in the pan-sharpening task.	• Failed to consider novel deep learning approaches in order to improve the pan-sharpening performance.
Azarang A and Ghassemian H., [15]	MRA	• Lower resolution PAN image was generated with respect to the high-resolution versions. • Images were fused to improve the pan-sharpening tasks	• The major challenge lies in optimizing the injected detail maps.
Ehlers M., *et al.* [16]	multi-sensor image fusion technique	• The superior-resolution multi-spectral images were obtained. • Achieved effective multi-sensor fusion by enhancing the spectral consistency	• Does not develop integrative quality indicator to improve the fusion results.
He L., *et al.* [18]	DiPAN	• Faster convergence results by enhancing the pan-sharpening quality. • Minimized the uncertainty in learning.	• Failed to design CNN with multiple hidden layers and numerous complex interconnections between one or more convolutional layers.
Li Z and Cheng C., [23]	CNN-enabled pan-sharpening	• To learn the complex mapping association among the MS images. • Achieved effective performance in various remote sensing areas.	• Unable to perform the parallel computation to decrease the time in the training phase.
	Image fusion-based techniques		
Palubinskas G., [4]	knowledge-based image adjustment technique	• Achieved effective performance by decreasing the computational complexities.	• Failed to utilize the PAN band correction techniques.
Zhu XX and Bamler R [13]	sparse image Fusion algorithm	• Enhance the super resolution capability. • Achieved enhanced spectral and spatial resolution with the lowest spectral distortions.	• The major challenge lies in correlating the MS channels.
Masi G., *et al.* [19]	CNN	• Resolve the super-resolution issue. • Minimize the energy during the Pansharpening tasks. • Minimize the training complexities.	• Failed to consider loss functions for training the network with typical no-reference measures.
Khateri M and Ghassemian H [22]	self learning approach	• The spatial and the spectral information of the source images were efficiently constructed for the pan-sharpening tasks.	• The major challenge lies in utilizing optimization-driven techniques.
	Guided filter-based techniques		
Li X., *et al.*	guided filtering	• Refine the blocking edges in the upscaled multi-spectral images. • Achieved effective spectral relationship was computed between MS and PAN image.	• Failed to reduce the communication cost and overhead issues.
Qi W., *et al.* [17]	guided filtering and HCT	• Enhance the process of pan-sharpening in the remote sensing fields.	• Failed to resolve the computational complexity issues
Gao Y., *et al.* [21]	scale-aware pan-sharpening technique	• Effectively improved spatial resolution of MS images.	• Failed to improve the spatial resolution images to protect the spectral information.
	Optimization-based techniques		
Wenqing Wang, *et al.* [28]	optimization based adaptive CS fusion framework	• Measure the radiometric similarity among Pan Image and low-scale intensity image for better pan sharpening.	• Some important indexes, like spectral angle mapper were not considered.
Muhammad Murtaza Khan, *et al.* [29]	QNR	• The control parameters are optimized using evolutionary algorithm to support the reconstruction of synthesis image.	• It was unable to circumvent local dissimilarities among the PAN and MS images.
Jamal Saeedi and Karim Faez [31]	MOPSO	• Good spatial similarity was the major advantage of this method.	• Local parametric estimation was needed to be improved.
Devi, *et al.* [32]	Lagrange Optimization and image fusion	• It enhanced the spectral consistency and offered better performance results than the existing methods.	• Different kind of input data were affects the performance of this method.
	Other Pan sharpening techniques		
AlcarasE., *et al.* [1]	GIS basic functions	• It performed the complicated pan sharpening tasks	• Failed to incorporate various pan-sharpening techniques for

			maximizing the overall available choices.
Smadi AA., *et al.* [5]	Kernel-based image filtering	• Improve the MS band from the PAN image. • Achieved effective image fusion process with enhanced computational effectiveness.	• Failed to consider the local linear filters in order to enhance the image fusion process.
Lee J., *et al.* [6]	shift-invariant pan-sharpening	• To reduce the local misalignments, for effective pan-sharpening performance.	• Failed to resolve the computational complexity issues
Mankar R., *et al.* [8]	FTIR	• This technique was more appropriate for the biomedical images with the curved discontinuities. • Enhance the spatial-spectral quality.	• Failed to utilize data acquisition techniques for offering high resolution data with minimized computational time.
Fu X., *et al.* [9]	variational pan-sharpening approach	• Enhance the generalization ability. • Achieved effective performance in maximizing the spatial resolution of fused results.	• Unable to use different segmentation approaches for evaluating the injection coefficients.
Restaino R., *et al.* [10]	Context-adaptive Pansharpening approach	• To achieve effective trade-off among the computational complexity and the accuracy.	
Saxena, N. and Sharma, K.K., [20]	HVD	• This technique effectively improved the spatial and spectral quality.	• Failed to resolve the computational complexity issues.
Yang Y., *et al.* [24]	MM	• MS image with the higher resolution is obtained effectively in the pan-sharpening fields.	• Failed to enhance the efficiency of the method
Wang, P., *et al.* [25]	MAP	• Effectively generated the enhanced resolution image. • To enhance the classification accuracy, and the computational efficiency.	• Failed to reduce the communication cost and overhead issues.

3. Research Gaps and Issues

This section illustrates several research gaps and issues faced by the Pansharpeningmethods, and are explained below as follows: The research issues faced by neural network-driven methods are described as follows: In [2], the devised approach failed to explore the utilization and extraction of the multi-scale features with respect to the deep CNN for reducing the network complexity issues. The introduced technique in [7] does not consider the MS and the hyper spectral image fusion approaches in order to enhance the performance of the network. In [11], the major challenge lies in utilizing suitable cropping mechanisms for reducing the computational cost, and the data resources. The devised technique in [14] failed to consider novel deep learning approaches in order to improve the pan-sharpening performance. In [15], the major challenge lies in optimizing the injected detail maps for efficient pan-sharpening. The designed approach in [16] does not develop integrative quality indicator in order to improve the fusion results. The devised approach in [18] failed to design CNN with multiple hidden layers and numerous complex interconnections between one or more convolutional layers for improving the performance of the system. In [23], the major challenge lies in performing parallel computation to decrease the time in the training phase.

Following are the research issues faced by the image fusion-based techniques are elucidated below as follows: The introduced technique in [4] failed to utilize the PAN band correction techniques for improving the optimization-driven pan-sharpening techniques. In [13], the major challenge lies in correlating the MS channels in order to achieve effective results. The introduced approach in [19] failed to consider loss functions for training the network with typical no-reference measures in order to enhance the pan-sharpening performance. In [22], the major challenge lies in utilizing optimization-driven techniques for enhancing network performance. The research problems faced by the Guided filter-enabled techniques are as follows, the designed approach in [21] failed to improve the spatial resolution images to protect the spectral information. Following are the various research problems faced by the other approaches and are illustrated given as follows: In [1], the introduced approach failed to incorporate various pan-sharpening techniques for maximizing the overall available choices for the user, and the accuracy-based evaluation. The proposed approach in [5] failed to consider the local linear filters in order to enhance the image fusion process. The newly designed technique in [6] failed to resolve the computational complexity issues. The developed approach in [8] failed to utilize data acquisition techniques for offering high resolution data with minimized computational time. In [10], the major challenge lies in utilizing different segmentation approaches for evaluating the injection coefficients. The devised method in [24] failed to enhance the efficiency of the method by utilizing wavelet-based functions along with the multi-resolution analysis tools. The designed approach in [25] failed to reduce the communication cost and overhead issues.

4. Analysis and Discussion

The analysis and discussion of Pansharpening methods based on different research papers with respect to the classification of techniques, publication year, and performance evaluation metrics are illustrated in this section.

4.1 Analysis using Published Year

The review for the Pansharpening techniques based on the publication year of 30 different research papers is explained in this section. The assessment based on published year is given in table 2. Among the 30 different papers reviewed, in 2021 the maximum research papers were published.

4.2 Analysis using Methods

This section describes the review based on several Pan-sharpening techniques. The different techniques utilized for the Pansharpening approaches are portrayed in figure 2. Using figure 2, it is shown that 31% of the research papers utilized neural network approaches, the optimization approaches were used in 17%, the image fusion techniques were used in 10%, and 10% of the researches utilized active Guided filter-based methods. Hence, from the analysis neural network-based methods are the most commonly used techniques for Pansharpening.

Table.2. *Analysis using publication year*

Publication year	Number of research papers
2021	8
2020	2
2019	4
2018	1
2017	7
2015	1
2016	3
2013	1
2011	1
2010	1
2008	1

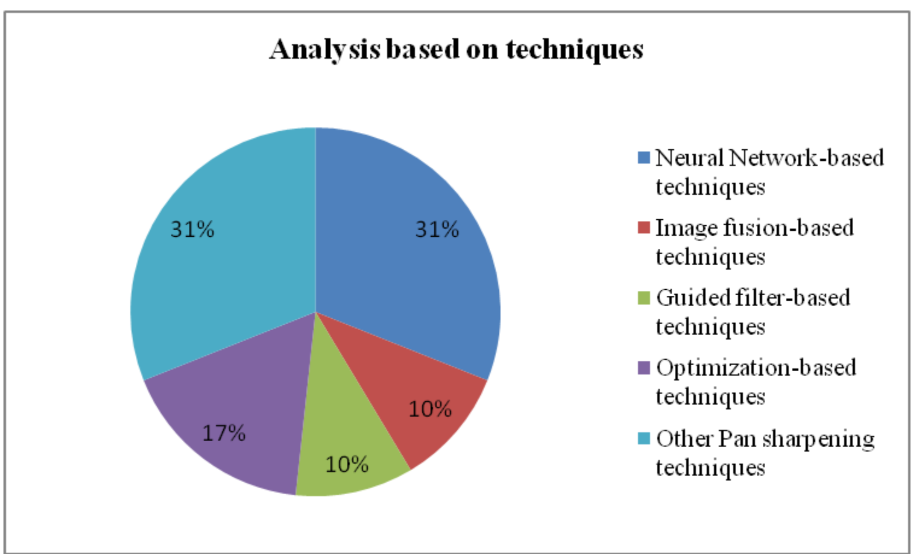

Fig.2. *Analysis using the classification of Pan-sharpening methods.*

4.3 Analysis using Evaluation Metrics

The performance evaluation metrics are analyzed in this section. Root Mean Square Error (RMSE), Accuracy, Peak-Signal-to-Noise-Ratio (PSNR), Quality-with-No-Reference (QNR), Spatial Correlation Coefficient (SCC), CC, SAM, Mean Square Error (MSE), Structural Similarity Index Measure (SSIM) are the various evaluation metrics considered for Pansharpening. From table 3, it is clearly shown that the SAM metric is the most widely used performance metric.

4.4 Analysis using Values of Performance Metrics

The assessment using values of evaluation metrics presented in this section. The analysis using SAM metric is illustrated in this section.

4.4.1 Evaluation Based on Sam Metric

In this technique, the evaluation based on the SAM metric is illustrated. Table 4 shows the review based on the SAM metric, and is specified by four ranges as, 0-2, 2-4, 4-6, 6-8. From the below table, it is clearly shown that the research article [15] [17] achieved higher SAM value and [10] [13] [14] [19] [24] research papers had low SAM value.

5. Conclusion

Remote sensing technology has played a significant role in various applications. The major goal of this survey is to analyze several existing pan-sharpening techniques. The reviews are gathered from 30 research works and gathered research papers are from IEEE explore, Google scholar, and Science direct with respect to the. The existing pan-sharpening techniques as Neural Network-enabled methods, Image fusion-enabled methods, Guided filter-enabled methods, and Optimization-enabled methods. Also, the analysis and discussion of the survey paper are illustrated using categorization methods, performance evaluation metrics, and publication year. Based on the assessment, it is noted that the Neural Network-enabled approaches are the most commonly utilized technique, and the evaluation metric SAM is the commonly utilized metric in many of the research papers. The future scope is to implement an efficient pan-sharpening approach based on the limitations recognized from the existing pan-sharpening techniques.

Table.3. *Assessment based on evaluation metrics*

Performance metrics	Number of Research papers
RMSE	[1] [4] [13] [14] [21] [23] [30] [31]
Accuracy	[2] [8] [28] [29]
PSNR	[3] [6] [32]
QNR	[5] [6] [7] [9] [10] [11] [19] [20] [21] [22] [24]
SCC	[1] [6] [12] [18]
CC	[1] [12] [13] [14] [15] [16] [17] [21] [22] [24] [25]
SAM	[8] [10] [11] [12] [13] [14] [15] [17] [18] [19] 20] [22] [23] [24]
SSIM	[15]
MSE	[15]

Table.4. *Analysis of SAM measure*

Range	SAM measure
0-2	[10] [13] [14] [19] [24]
2-4	[8] [18] [23]
4-6	[11] [12] [20] [22]
6-8	[15] [17]

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

References

[1] Alcaras E, Parente C, Vallario A., "Automation of Pan-Sharpening Methods for Pléiades Images Using GIS Basic Functions", Remote Sensing, vol.13, no.8, pp.1550, January 2021.

[2] Liu Q, Han L, Tan R, Fan H, Li W, Zhu H, Du B, Liu S., "Hybrid Attention Based Residual Network for Pansharpening", Remote Sensing, vol.13, no.10, pp.1962, January 2021.

[3] Xu S, Zhang J, Sun K, Zhao Z, Huang L, Liu J, Zhang C., "Deep Convolutional Sparse Coding Network for Pansharpening with Guidance of Side Information", March 2021.

[4] Palubinskas G., "Model-based image adjustment for a successful pan sharpening", March 2021.

[5] Smadi AA, Yang S, Mehmood A, Abugabah A, Wang M, Bashir M., "Smart pansharpening approach using kernel-based image filtering", IET Image Processing, 2021.

[6] Lee J, Seo S, Kim M., "SIPSA-Net: Shift-Invariant Pan Sharpening with Moving Object Alignment for Satellite Imagery", May 2021.

[7] Wang W, Zhou Z, Liu H, Xie G., "MSDRN: Pansharpening of Multispectral Images via Multi-Scale Deep Residual Network", Remote Sensing, vol.13, no.6, pp.1200, January 2021.

[8] Mankar R, Gajjela C, Foroozandeh F, Prasad S, Mayerich D, Reddy R., "Multi-Modal Image Sharpening in Fourier Transform Infrared (FTIR) Microscopy", Analyst, 2021.

[9] Fu X, Lin Z, Huang Y, Ding X., "A variational pan-sharpening with local gradient constraints", InProceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, pp.10265-10274, 2019

[10] Restaino R, Dalla Mura M, Vivone G, Chanussot J., "Context-adaptive pansharpening based on image segmentation", IEEE Transactions on Geo science and Remote Sensing", vol.55, no.22, pp.753-66, December 2016.

[11] Vitale S, Scarpa G., "A detail-preserving cross-scale learning strategy for CNN-based pan sharpening", Remote Sensing, vol.12, no.3, pp.348, January 2020.

[12] Li X, Qi W, Yue S., "An effective pansharpening method based on guided filtering", In proceedings of 11th Conference on Industrial Electronics and Applications (ICIEA), IEEE pp.534-538, June 2016.

[13] Zhu XX, Bamler R., "A sparse image fusion algorithm with application to pan-sharpening", IEEE transactions on geo science and remote sensing, vol.51, no.5, pp.2827-36, October 2012.

[14] He L, Zhu J, Li J, Plaza A, Chanussot J, Li B., "HyperPNN: Hyperspectral pansharpening via spectrally predictive convolutional neural networks", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol.12, no.8, pp.3092-100, June 2019.

[15] Azarang A, Ghassemian H., "A new pansharpening method using multi resolution analysis framework and deep neural networks", In proceedings of 3rd International Conference on Pattern Recognition and Image Analysis (IPRIA), pp.1-6, April 2017.

[16] Ehlers M, Klonus S, Johan Åstrand P, Rosso P., "Multi-sensor image fusion for pan sharpening in remote sensing", International Journal of Image and Data Fusion, vol.1, no.1, pp.25-45, March 2010.

[17] Qi, W., Li, X. and Yue, S., "A guided filtering and HCT integrated pansharpening method for WorldView-2 satellite images", In proceedings of International Geoscience and Remote Sensing Symposium (IGARSS), IEEE,pp.7272-7275, July 2016.

[18] He L, Rao Y, Li J, Chanussot J, Plaza A, Zhu J, Li B., "Pansharpening via detail injection based convolutional neural networks", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol.12, no.4, pp.1188-204, March 2019.

[19] Masi G, Cozzolino D, Verdoliva L, Scarpa G., "Pansharpening by convolutional neural networks", Remote Sensing, vol.8, no.7, pp.594, July 2016.

[20] Saxena, N. and Sharma, K.K., "A hybrid approach for pansharpening using Hilbert vibration decomposition", In proceedings of International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), IEEEpp.2801-2805, September 2017.

[21] Gao Y, Li X, Gao A, Li L, Yue S., "A scale-aware pansharpening method with rolling guidance filter", In proceedings of International Geoscience and Remote Sensing Symposium (IGARSS), IEEEpp.5121-5124, July 2017.

[22] Khateri M, Ghassemian H., “A self-learning approach for pan-sharpening of multispectral images”, In proceedings of 2017 IEEE International Conference on Signal and Image Processing Applications (ICSIPA), pp.199-204, September 2017.

[23] Li Z, Cheng C., “A CNN-based pan-sharpening method for integrating panchromatic and multispectral images using Landsat 8”, Remote Sensing, vol.11, no.22, pp.2606, January 2019.

[24] Yang Y, Wan W, Huang S, Lin P, Que Y., “A novel pan-sharpening framework based on matting model and multiscale transform”, Remote Sensing, vol.9, no.4, pp.391, April 2017.

[25] Wang, P., Wang, L., Wu, Y. and Leung, H., “Utilizing pansharpening technique to produce sub-pixel resolution thematic map from coarse remote sensing image”, Remote Sensing, vol.10, no.6, pp.884, 2018.

[26] Lei Wu, Yunqiang Yin, Xunyan Jiang, and T.C.E.Cheng, "Pan-sharpening based on multi-objective decision for multi-band remote sensing images," Pattern Recognition, vol. 118, 2021.

[27] Cheng Jin, Liang-Jian Deng, Ting-Zhu Huang, and Gemine Vivone, "Laplacian pyramid networks: A new approach for multispectral pansharpening," Information Fusion, vol. 78, pp. 158-170, 2022.

[28] Wenqing Wang, Licheng Jiao, and Shuyuan Yang, "Novel Adaptive Component-Substitution-Based Pan-Sharpening Using Particle Swarm Optimization," IEEE Geoscience and Remote Sensing Letters, vol. 12, no. 4, pp. 781 - 785, 2015.

[29] Muhammad Murtaza Khan, Luciano Alparone, and Jocelyn Chanussot, "QNR Optimization based Pansharpening," In the proceeding of IGARSS 2008 - 2008 IEEE International Geoscience and Remote Sensing Symposium, IEEE, Boston, MA, USA, 2008.

[30] Yingxia Chen and Guixu Zhang, "A Pan-Sharpening Method Based on Evolutionary Optimization and IHS Transformation," Mathematical Problems in Engineering, vol. 2017, 2017.

[31] Jamal Saeedi and Karim Faez, "A new pan-sharpening method using multiobjective particle swarm optimization and the shiftable contourlet transform," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 66, no. 3, pp. 365-381, 2011.

[32] Devi, Mutum Bidyarani, Devanathan, and Rajagopalan, "Evaluation of Pan-Sharpening Techniques Using Lagrange Optimization," Advances in Technology Innovation, vol. 5, no. 3 pp. 166-181, 2020.