Machine Learning based Image Processing Techniques for Satellite Image Analysis -A Survey

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***Abstract*— This paper presents the detailed comparison of various image processing techniques for analyzing satellite images .The satellite images are large in size, acquired from long distances and are affected by noise and other environmental conditions .Hence it is necessary to process them so that they can be used by the researchers for analysis. Satellite images are widely used in many real time applications such as in agriculture land detection, navigation and in geographical information systems. In this paper, a review of some popular machine learning based image processing techniques is presented. Also a detailed comparison of various techniques is performed. Limitations in each image processing method are also described. In addition to reviewing of different methods, different metrics for performance evaluation in each of the image processing areas is studied.**

***Keywords*—Remote Sensing. Machine Learning, Segmentation, Enhancement, Feature Extraction.**

I. Introduction

With the advances in technology, digital image processing is now used frequently. Satellites capture remote sensing images which find various applications in agriculture, defence, navigation and so on. With the years, there has been a vast improvement in satellite image capturing techniques and so the image size has also increased. For such images, archival for future purposes is difficult. It requires a lot of processing time. Various image processing techniques can be adopted which can change some of the image features for better clarity and storage.

The satellite images differ widely in terms of the textural contrasts, colour variations and also are quite complex due to the presence of these variations. Hence applying processing techniques on the satellite data is quite difficult. Also the satellite data is captures from long distances and is affected by the presence of unwanted interferences which affects the quality of the image. This poses a serious difficulty in the succeeding processing stages and reduces the overall quality of the final image. The final image is very much essential for future analysis and for decision making purposes. Hence the noise distorted satellite images should be pre-processed before further processing techniques on the image is carried out. Fig 1 shows a sample Landsat image. Nowadays remote sensing has proven to be a rapidly improving technology for acquiring satellite data and is very much important for analysing the spatio-temporal changes on the earth's surface. This data is collected by researchers and government organizations around the world for analysing the earth's changes. Remote sensing data is particularly useful in areas including global climate change estimation, land cover change detection, environmental monitoring as part of disaster management, urban and land development, security, to name a few.

This paper briefly explains the various image processing techniques adopted on satellite images such as image enhancement, image fusion, image object detection, image segmentation, classification, image feature detection.

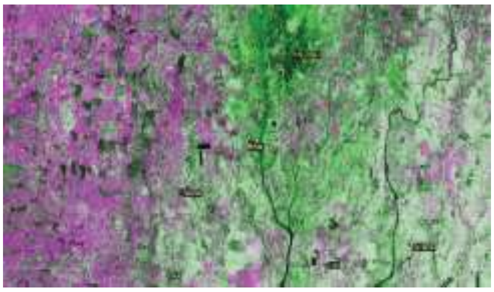

Fig 1: Landsat 7 Image of Resolution 921 × 593

II. Algorithms

There are various mathematical approaches and algorithms introduced which can be used for satellite image processing. The satellite image processing techniques discussed are enhancement, segmentation, feature extraction, fusion and feature detection. Fig 2 shows the satellite image processing techniques.

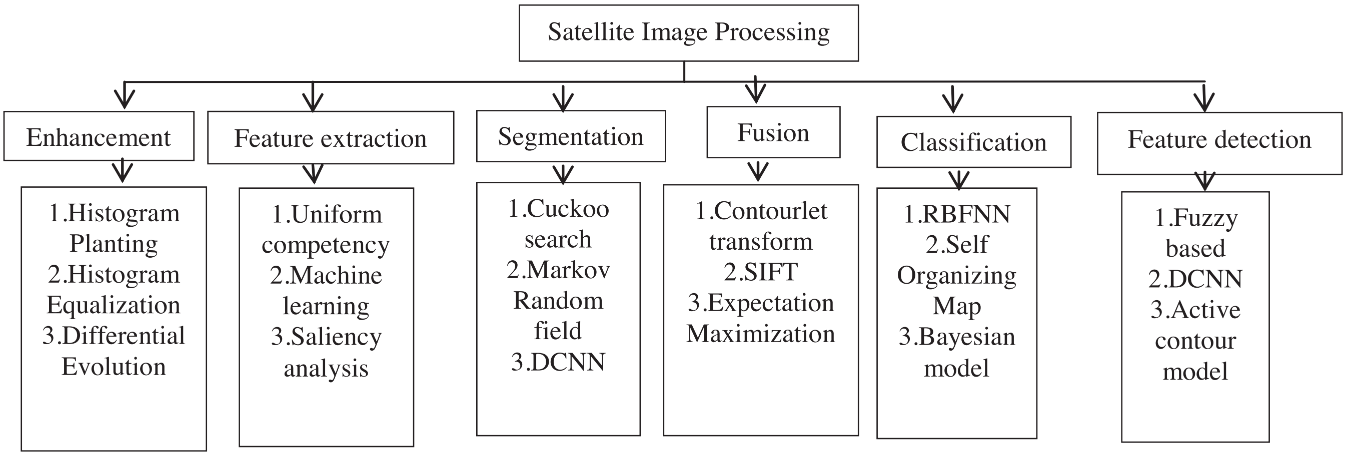

Fig 2: Satellite Image Processing Techniques

A.Image Enhancement

Satellite images usually contain narrow brightness level. This enables the need for enhancing these images but the important details need to be retained without loss of information. Image enhancement techniques can be broadly classified as: spatial and frequency domain techniques. Histogram Equalization is one of the prominent image enhancement techniques which can be applied to a whole image or some extracted part in an image. It is used to improve the overall visual appearance of the image. Various metaheuristic based algorithms are in trend today. Particle Swarm Optimization (PSO) is one such algorithm which is used for image enhancement. Some classical evolutionary computation algorithms are also being used for image enhancement. Another proposed method to enhance the contrast of a gray-level image was done using Genetic Algorithm (GA) which measures the fitness of an individual. This is done by finding the intensity of spatial edges in the image. Another prominent method is using the transformation functions to produce an enhanced image by GA. This method seems to perform fairly well to enhance the image. But the GA and PSO method suffer from the limitation that they get trapped in local minima.
TABLE I shows the comparison for image enhancement.

TABLE I Comparison for Image Enhancement

Author	**Artifacts**	**Method**
1. Y.C. Chang(2017)[1]	Contrast and brightness	Histogram Planting
2. S. Suresh and S. Lal (2017)[2]	Contrast and brightness	Modified differential evolution
3.H.Singh, A. Kumar , L.K. Balyan and G.K. Singh (2017)[3]	Dark image enhancement	Fractional Differential (FD) unsharp masking

Combining various optimization techniques have also received great interest in recent years. One such method is combining the Cuckoo Search(CS) and the Particle Swarm optimization algorithm. Cuckoo search is a population based global search algorithm. On combining the CS with PSO algorithm has shown better results in terms of closeness to optimal solution when compared to PSO or GA individually. Another popular method is the Modified Differential Evolution (MDE) algorithm along with the CS algorithm which is also widely used for image enhancement [2].

B.Feature Extraction

Feature extraction is the process by which features are generated for use in selection and classification. Those features which have a potential for differentiation is selected and utilized for classification procedure. Scale Invariant Feature Transform (SIFT) and scale- invariant feature operator (SFOP) are the most prominent feature extraction techniques which utilizes scale space theory to find both scale and the location of local features.

Also point feature detection algorithm such as FAST is also prevalent. A feature matching algorithm based on graph theory is used in [2]. This method suffers from non-linear intensity differences. K-Means Clustering is yet another algorithm which has been used over the years for separation of different features from the background. It is an unsupervised algorithm where the user can specify the number of clusters by which the clustering can proceed.

But statistical methods such as Machine Learning is currently used. A method utilizing machine learning along with Euclidean distance is used for feature extraction [3]. This method takes the satellite product as input and detects features such as river from it in the form of an image. The main aim is to find out the feature blocks from the image using a machine learning technique. Here REPTree is used which takes multiple iterations to develop trees . The three best among them are selected. Saliency analysis is also being used for feature extraction. A method to generate multi image saliency map from multispectral and panchromatic images by computing their saliency maps individually is used in [4]. This method uses the similar features in a set of images to find the saliency maps. The main drawback faced as part of feature extraction is that very high structures are underestimated due to certain image disparities. Also there are some matching errors introduced due to shadows in the scenes. TABLE II shows the comparison for feature extraction.

TABLE II Comparison for Feature Extraction

Method	Feature Extracted	Limitations
1. Multi image saliency analysis[4]	ROI extraction such as clouds	Presence of unwanted background information
2. Uniform Competency Feature Extraction[5]	Rotation and scale invariant Local features	Varying matching results for different data
3. Digital Surface Models [6]	Pixel and feature level extraction of urban scenes	Difficulty in multi feature classification
4. Reversible jump Markov chain Monte Carlo sampler[7]	Extraction of rivers, channels and roads	Sensitivity to experimental settings

C.Image Segmentation

Image segmentation deals with categorizing the pixels in an image into different classes such that there exists some correlated portions of the image in each cluster. It has its importance when trying to identify certain significant areas in an image such as forest cover, urban areas, disaster prone areas etc. With the introduction of metaheuristic algorithms, the researchers are expanding their research into segmentation by combining such algorithms.

Recently, segmentation methods using Convolutional Neural Network (CNN) features and Conditional Random Fields (CRFs) have been proposed which provides segmentation with high accuracy. Modeling the segmentation problem using Support Vector Machines (SVM) is yet another widely used method. A framework using deep convolutional networks for image segmentation finds wide use in applications where buildings are to be segmented from the background. This method uses supervised classification utilizing a large training dataset. The classification could be improved using a Markov Random Field (MRF) as proposed in [5]. TABLE III shows the comparison form image segmentation.

The method used involves quantization, clustering and finding the likelihood with only minimum number of clusters. A Deep Convolution Neural Network (DCNN) for semantic segmentation in high resolution satellite images is suggested in [6]. In this method, first, a novel model is developed by adding boundary detection to a SEGNET encoder. It is a combination of a convolutional network and an encoder. But the major drawback in the model is its excessive size of the model which is matter of concern for researchers using this model. Also the extracted boundaries are very blurry.

TABLE III Comparison for Image Segmentation

Author	Segmentation	Advantages
1.S. Suresh and S. Lal (2016)[6]	Cuckoo Search,McCulloch's method	Computationally efficient and better convergence
2. I. Grinias , C. Panagiotakis , G. Tziritas (2016)[7]	Markov Random Filed method	Better classification accuracy with less visual and shape features
3. D. Marmanis et al.(2017)[8]	Deep convolutional Neural Network	Efficient boundary extraction improves classification
4. S. Pare , A.K. Bhandari , A. Kumar , and G.K. Singh(2017)[9]	Levy flight firefly algorithm	Good level of multilevel segmentation with minimum computation time

D.Image Fusion

Image fusion is a process by which a new image is created which combined two or more images. The main aim of such fused images is to retain as much source information as possible and it is expected that the fused image will be better than, or at least as good as, the performance of input images. Fig 3 shows the general block diagram of the fusion method. Image fusion techniques can be classified as: pixel based, feature based and decision based. The most commonly used method involves arithmetic computation technique such as Bovey Transform (BT) and Synthetic Variable Ratio (SVR).But the method suffers from the drawback that it is not efficient to quickly merge such large volumes of satellite data.

Recently there are some geometric analysis tools which are applied for image fusion based on transforms such as curvelet transform, contourlets transform, wedgelet transform and Non Subsampled Contourlet Transform (NSCT). For the satellite images, it is important to analyze its geometric structure .For this, the Shift-Invariant Shearlet transform (SIST) is proposed for remote sensing image fusion [7]. As the first step the feature vectors of multispectral and panchromatic images are extracted and then they are divided into different regions using Fuzzy C Means (FCM). The SIST gives the representation of the first principal component of the multispectral image. The principal component in an image is obtained using entropy component analysis and panchromatic images.

Various model based methods are also being used in the area of image fusion. One such method is a hierarchical Bayesian model to fuse multiple multi-band images. Image fusion based on image decomposition and sparse representation is proposed in [8]. Here the input image is divided into cartoon and texture components. The fusion of the cartoon components is carried out using a spatial based fusion. The fusion of textural components is carried out using sparse representation based fusion.

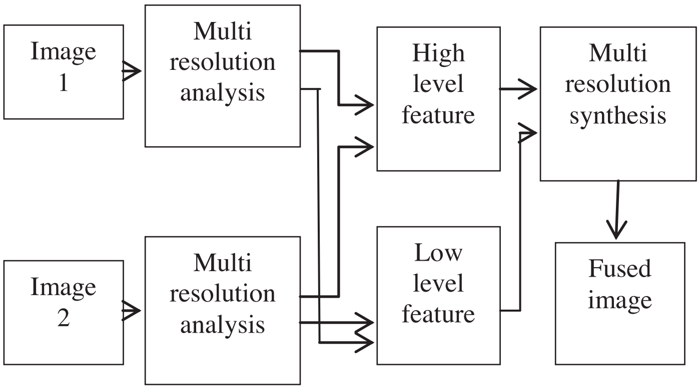

Fig 3: General Block Diagram of Image Fusion

Spatial inconsistency in fused images is overcome using dictionary learning method for fusing the textural components in the image.

One of the major drawbacks in a fused image is that there can be some noise effects which reduce the pleasing effects in such images. A spider optimization based algorithm produces two enhanced images, one with high contrast and the other with high peak signal-to-noise ratio (PSNR) image [9]. This search algorithm has the entire search space considered as a web, the agents being the spiders and optimal solution is represented by the spider's position in the web. An output image is created which is formed by fusing both these images which has a tradeoff between noise and contrast. This method balances contrast and PSNR compared to other image enhancement methods such as Histogram Equalization (HE), Linear Contrast Stretching (LCS), and standard Particle Swarm Optimization (PSO) algorithm. A method for the classification of a scene based on the spatial fusion of local and global features in the image is proposed in [10]. The image is partitioned into dense regions and then the k-means clustering method is applied.

A multi modal feature based fusion is one in which two feature extractions are involved [11]. The first is the deep feature extraction and the second the shallow feature extraction. The low level features are extracted for each pixel in the image which is the shallow feature extraction using SIFT followed by the deep feature extraction using convolutional neural networks. From the low level features extracted, the mid-level features are developed. Lastly high level features are developed from the mid-level features using Deep Belief Networks (DBN). Then using a Restricted Boltzmann Machine (RBM), correlation between the deep and shallow extracted features is studied using which image fusion is performed. Based on the evaluated annotation efficiency, it is concluded that multi modal fusion performs better than single modal fusion. The most visible drawback in most of the used fusion methods is that it fails to capture the smoothness between different contours.

E.Image Classification

A number of factors are to be considered when trying to classify the satellite images based on some features in the image. There is a need to design efficient classification algorithm based on the user's requirement, the spatial resolution of the remote sensing image, present image classification, other processing algorithms and also the time factor. The classification should be such that each of the regions is easily separable, independent and should give enough information for the purpose of analysis.

For better processing of the image, satellite image classification can be followed by other stages such as denoising, segmentation for extracting the features in the image , enhancement and so on. Also the image classification is dependent on the type of satellite images which are used since different satellites provide different images varying with the type of the sensors. TABLE IV gives the image classification methods and the performance metrics used.

Most commonly used methods for image classification include artificial neural network, fuzzy algorithms and expert systems. Radial Basis Function Neural Network(RBFNN) is a very effective neural network which has a large number of tunable parameters[13]. The main advantage of this method is its immunity to noise signals.

TABLE IV Performance Metrics for Image Classification

Method	Test Images	Application	Performance Metrics
1.Radial Basis Function Neural Networks[13]	Landsat 8 images	Flood area classification	Accuracy and kappa coefficient
2.Bagger algorithm, SVM and KNN	NASA EO-1 satellite images	Agricultural land classification	Overall accuracy
3.Kohonen Self Organizing Map	NASA AVIRIS sensor based satellite image	Crop variation classification	Accuracy and kappa coefficient
4.Bayesian Network Classifier[12]	Visible and IR images	Cloud classification	Precision and F-measure

Image classification in Unmanned Aerial Vehicle (UAV) images is another category. Here the machine learning using SVM is one of the most commonly used method and a classification map is generated based on the result. The basis function used for the classification is the radial basis function. But the SVM does not guarantee accurate results and there are some errors in the classification. Supervised method for object based classification is currently the most widely used method. But the fuzzy based techniques are limited for object based classification [14].

Random Forest (RF) is another widely used classification algorithm. There are both supervised and unsupervised classification algorithms. In supervised classification, two main methods are most commonly used. The first is based on the Fitting equation. Here the fitting equation is substituted with the mean area of the reference objects to compute the different classification scales. Another method is using the Euclidean distance for the reference and the input object. Under the unsupervised method, is the rate of change (ROC) method which is found by obtaining the difference between two indices to get the corresponding optimized solution. The different classification methods find applications in different areas. RF method is used in the habitat based forest classification, urban land use classification and land cover classification. SVM finds wide use in detecting landslide affected areas and land cover classification. GA finds use in forest mapping. RF in combination with SVM is used for agricultural area classification and disaster prone area division.

A deep feature learning method for the classification in high resolution satellite images is proposed in [15]. First the image is divided into different scales and the images in each scale are employed for training the DCNN. The training process can be accelerated using spatial pyramid pooling (SPP). The SPP nets can take different image scales and they have the same weight parameters. Also modifying the parameters in fully connected model speeds up the training process in each SPP net. During the classification method, optimization of the weight is done using multiple kernel learning. Combining different classification models by assessing the classification accuracy can improve the quality of the final outcome.

F.Image Feature Detection

Feature recognition is a topic of increasing interest with the recent developments in deep learning. The ability to distinguish various features in the image, such as buildings, roads, vegetation and other categories, could be of help in various applications such as improving urban planning, environment monitoring, identifying the disaster prone areas and so on. Edge detection is an important application in the field of image processing. Currently various edge detection techniques such as PSO , Preweitt, Laplacian and Laplacian of Gaussian are being used. The disadvantage of this technique is that the edge thickness is fixed and implementation of threshold is difficult.

An efficient oil spill detection in sea is required by the International Maritime Organization to carry out evaluation of trade routes through sea. This requires a feature selection based on machine learning algorithm [16]. The SAR images are widely used to provide images on the oil spills on the surface of the ocean. It can provide wide area coverage and good image clarity. The oil spill detection has three main stages. In the first stage, the feature is separated from the background using dark spot segmentation. In the second stage, feature extraction is done to get the feature vectors which contain information to distinguish oil spills from the rest of the image. In the third stage, dark spot classification is done where the distinction criteria between the feature and non-feature regions is performed. Feature Selection is the most prominent step in the machine learning process which creates a set of features which clearly describe the detection problem.

One of the main drawbacks faced is the presence of the clouds which affect the image quality in satellite images. This makes it difficult for the researcher who is trying to get some information regarding the terrain. Hence cloud detection becomes necessary as part of satellite image processing. The panchromatic satellite images make the cloud detection difficult since the cloud distribution is highly irregular.

III. PERFORMANCE EVALUATION

The performance of the developed algorithms can be measured both quantitatively and qualitatively. Qualitative evaluation is highly subjective and for qualitative evaluation various parameters are to be computed and compared with the available techniques to understand the suitability and the reliability of the proposed technique over the existing literature. A few of the computed parameters include Feature Similarity Index (FSIM), Structural Similarity Index (SSIM), precision and recall. Feature Similarity Index or FSIM denotes the similarity of features between the input image and the final image .It is calculated using equation (1):

$$FSIM = \frac{\sum_{x \in X} S_L(x) PC_m(x)}{\sum_{x \in X} PC_m(x)} \tag{1}$$

where X represents the whole image, $S_L(x)$ represents the similarity in the two images and PC_m is the phase congruency map.

Structural Similarity Index (SSIM) denotes the structural similarity between the input image and the final image. It is computed using equation (2) :

$$SSIM = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{2}$$

where μ_x and μ_y are the sample means of x and y, respectively; σ_x and σ_y give the sample variances of x and y, respectively; and σ_{xy} shows the sample correlation coefficient between x and y and x and y are local windows in the input images.

Precision is the ratio of correctly predicted positive observations to the total predicted observations. It is calculated using equation (3) :

$$\text{Precision} = \frac{\sum_{i=1}^{N} GT_i . BW_i}{\sum_{i=1}^{N} BW_i} \tag{3}$$

Where BW_i is the i^{th} pixel in a binary map and $GT_i = 1$ is the i^{th} pixel that belongs to a region of and interest $GT_i = 0$ indicates that the pixel is not present in ROI.

Recall is the ratio of correctly predicted positive observations to the total observations in the class. It is calculated using equation (4):

$$\text{Recall} = \frac{\sum_{i=1}^{N} GT_i . BW_i}{\sum_{i=1}^{N} GT_i} \tag{4}$$

F1 score is obtained by the weighted average of Precision and Recall. Hence this metric takes both false positives and false negatives into account. Accuracy assessment using kappa coefficient is another metric. It summarizes the accuracy assessment for remote sensing classification.

IV. CONCLUSIONS

The frequent availability of satellite images has made the remote applications flourish. Some of the common challenges found in the literatures are the image complexity, large image sizes, presence of unwanted artifacts and background information in the satellite images. It is especially difficult in feature detection in panchromatic images due to the presence of cloud cover. Most image fusion techniques suffer from the drawback that it cannot capture the smoothness between the contours. On examining the literature it is seen that deep learning and hybrid machine learning based techniques are finding wide popularity recently. Also deep learning techniques can be used as part of supervised image classification and would be helpful in minimizing the misclassification errors and hence improving the overall classification accuracy. In this paper, we have discussed various image processing techniques, existing algorithms and the improved algorithms which could overcome the limitations of the existing algorithm. Also the difference metrics for evaluating the overall performance of the image processing techniques are presented. Furthermore, new objective performance evaluation methods could be developed to validate these techniques. At present, even though a wide range of techniques are available for image processing, it is extremely cumbersome to arrive at a technique which can be commonly applied to all types of satellite images owing to the different color and textural variations. Hence presently the researchers are trying to arrive at some solutions by combining various image processing techniques or introducing hybrid models based on spectral and spatial indices for the same to improve the outcome.

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