



Deep Feature segmentation model Driven by Hybrid Convolution Network for Hyper Spectral Image Classification

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Abstract: Hyperspectral image (HSI) classification can support different applications, such as agriculture, military, city planning, land utilization, and identifying distinct regions. It is treated as a crucial topic in the research community. Recent advancement in convolution neural network (CNN) has shown the unique capability of extracting meaningful feature and classification. However, CNN works with square images with fixed dimensions and cannot extract local information of images having distinct geometric variations with context and content relationships; hence there is a scope for improvement in correctly identifying class boundaries. Encouraged by the facts, we propose an HSI feature segmentation model by the hybrid convolution network (GCNN-RESNET152) for the HSI classification. First, pre-trained CNN on ImageNet is used to obtain the multilayer feature. Second, the 3D discrete wavelet transform image is fed into the graph convolution network GCN model to gain patch-to-patch correlations feature maps. Finally, the features are integrated using the three weighted coefficients concatenation method. Finally, the linear classifier is used to predict the semantic classes of pixel HSI. The proposed model is tested on four benchmark dataset Houston University (HU), Indian pines(IP), Kennedy space station(KSS), and Pavia university(PU). The result is compared with state-of-art algorithms and found to be superior in terms of overall, average, and kappa accuracy. The Overall, average and kappa accuracy achieved for HU: 97.7%, 99.4%, 95.6%, IP: 97.7%, 99.4%, 95.6%, KSS:97.48%,99.68%,96.43%, and PU: 97.7%, 99.4%, 95.6% respectively, which is 5 to 8% more than state of art methods.

Keywords: Hybrid Convolution Network, Hyper-spectral image, classification, deep feature segmentation

1. INTRODUCTION

This The recent year witnessed hyperspectral image (HSI) classification in the military, irrigation, mining, and route detection [1, 2], as shown in Fig 1. Most machine learning ML algorithms such as K-nearest neighbor [3], support vector machine [4], Bayesian classifier [5], kernel-based method [6], and regression model [7] have been used for HSI classification [8, 9]. The major drawback of this ML is the manual extraction of features, which is time-consuming. Recently Deep learning algorithm has shown remarkable results with automatic feature extraction from raw images. HSI classification using deep learning is categorized into 1-D CNN [10,11], 2-D CNN [12-14], and 3-D CNN [15].

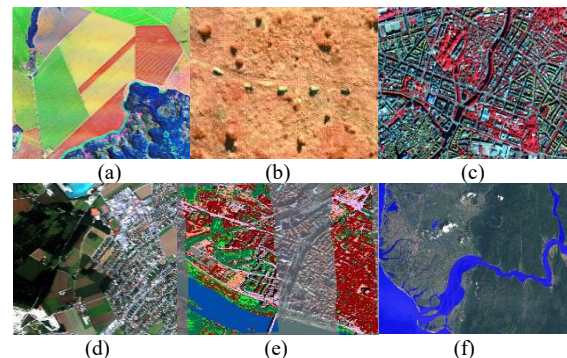


Figure 1. Real World application of Hyperspectral Image a) Corn Varieties showing HSI in agriculture [17] b) Military Surveillance or Tracking [18] c) Urban Green Observation [19] d) Land Utilization [20] e) City Planning [21] f) Flood Monitoring [22]

The CNN model has its limitation. During the training, it stuck in local minima or gradient descent. The pooling

layer can lose maximum information during pre-processing. In contrast, 3-D CNN is experienced as computationally costly and complex. On the other side, to capture the topological and geometric features of the geospatial image, the GCN model is found to be the most effective [16].

The CNN model [16], while a powerful tool in machine learning, does have its limitations. One notable issue arises during the training process when the model can become trapped in local minima or struggle with gradient descent convergence. This can hinder its ability to learn and generalize effectively. Another drawback lies in the pooling layer, which, during pre-processing, can lead to the loss of maximum information, potentially affecting the model's ability to discern critical features. In contrast to the CNN, the 3-D CNN, although capable of capturing intricate spatial information, is often considered computationally expensive and complex. This increased computational burden can hinder its practicality and efficiency in certain applications.

To address these challenges and leverage the strengths of both the CNN and the GCN (Graph Convolutional Network) models, we propose a novel approach—a deep feature segmentation model known as GCNN-RESNET152—for hyperspectral image (HSI) classification. This innovative hybrid model combines the ResNet152 architecture for global feature extraction and the GCN for context feature extraction from the 3D discrete wavelet transform image. By employing GCN, we can effectively reveal patch-wise correlations within feature maps, enhancing the model's ability to understand intricate spatial relationships.

The proposed approach follows a structured workflow:

- **Global Feature Extraction (ResNet152):** Initially, we employ the ResNet152 model to extract global features from the hyperspectral images. This step helps the model capture high-level information that is vital for accurate classification.
- **Context Feature Extraction (GCN):** Next, we utilize the Graph Convolutional Network (GCN) to extract context features from the 3D discrete wavelet transform image. This approach enables the model to capture intricate topological and geometric features of geospatial images, which are essential for precise classification.
- **Integration of Extracted Features:** Once we have both the global and context features, we integrate them using weighted methods. This fusion of information ensures that the model leverages the strengths of both feature extraction processes, enhancing its overall classification performance.
- **Classification with Linear Classifiers:** The

integrated features are then used to train and test a linear classifier. We explore various classifiers, including Support Vector Machine, Decision Tree, Naïve Bayes, K-Nearest Neighbors (KNN), and Extreme Machine Learning.

- Remarkably, our experimental results demonstrate that the Extreme Machine Learning classifier consistently outperforms the other classifiers in terms of classification accuracy. This indicates the effectiveness of our proposed hybrid model in providing discriminative features for accurate HSI classification.

Furthermore, we assess the overall performance of our approach by comparing its average accuracy and kappa accuracy with those of other state-of-the-art algorithms. Our results reveal that our method significantly outperforms these alternative approaches on four benchmark datasets: Indian Pines, Kennedy Space Station, Houston University, and Pavia University. This superior performance underscores the potential of the GCNN-RESNET152 model for hyperspectral image classification tasks.

The paper's organization is as follows; section II deals with materials and methods, and section III shows the proposed method GCNN-RESNET152. Experiment evolution and result analysis are discussed in Section IV. Section V deals with novelty and summary, followed by the conclusion and future work in section VI.

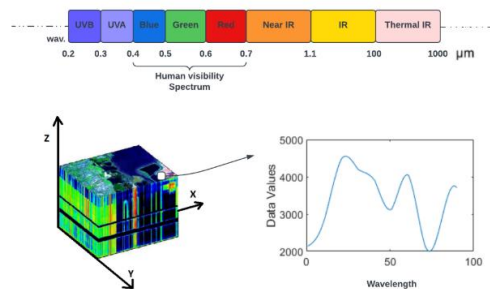


Figure 2. Pixel represent HSI, visualized as data cube, where (x, y) axis represent spatial information and z (lambda or wavelength) axis represent spectral information of image.

2. MATERIALS AND METHODS

A. Hyper spectral Imaging

Spectroscopy techniques play a crucial role in the field of Hyperspectral Imaging (HSI), a powerful

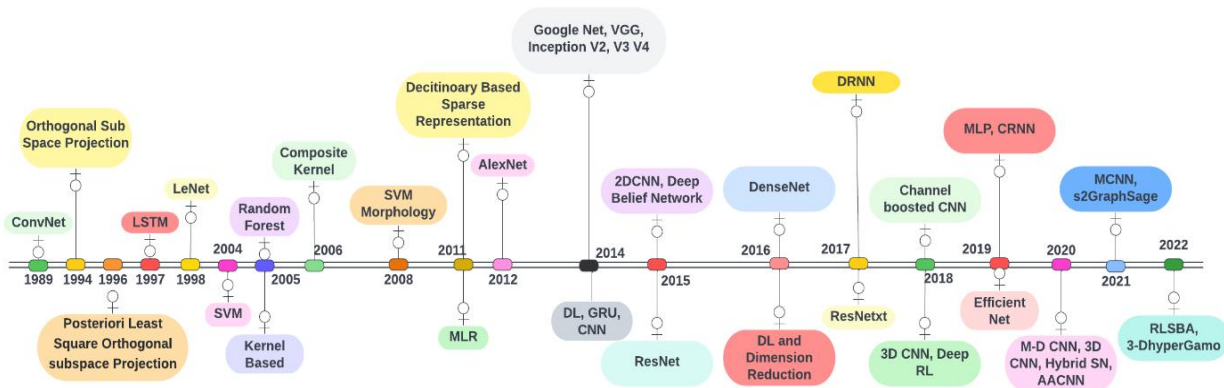


Figure 3. Most cited Research in the field of Hyperspectral Image classification year wise and Evolution of CNN

technology used to collect detailed information about objects or scenes. Unlike the human eye, which can perceive only three primary colors (blue, green, and red), HSI goes beyond this limitation by capturing images at numerous distinct wavelengths across a wide range, typically spanning from 0.1 to 1000 μm (micrometers). The fundamental concept of HSI involves breaking down the spatial area of interest into countless small regions, typically pixels. For each of these pixels, HSI records the intensity of light at multiple wavelengths. This data is then represented as a three-dimensional cube, commonly referred to as the "HSI cube."

This cube comprises three dimensions: X and Y Dimensions (Spatial Information): These represent the horizontal and vertical dimensions of the image, which correspond to its spatial extent. Essentially, it's the familiar 2D representation of the object or scene. λ Dimension (Spectral Information): This is the third dimension, which represents the spectral content or the wavelength information. It extends perpendicular to the X-Y plane. In essence, this dimension contains the information about the different wavelengths of light used to capture the image.

So, when you examine a HSI cube, you're looking at a composite image that combines spatial and spectral information. Each pixel within the cube represents a tiny piece of the overall scene and contains data about how light at different wavelengths interacts with that specific part of the object or scene.

To provide a visual representation, **Fig 2** illustrates this HSI cube. It's essentially a graphical depiction of the HSI data structure, with axes representing the spatial dimensions (X and Y) and the spectral dimension (λ). This cube is a fundamental

concept in hyperspectral imaging, serving as the basis for extracting valuable information about the materials, composition, and characteristics of the objects or scenes being observed. One important application of hyperspectral imaging is the classification of objects within the image. This involves the task of assigning a specific class label to every individual pixel in the image. This can be done using advanced machine learning and image processing techniques, allowing for the identification and analysis of specific features or materials within the scene.

B. Convolution Neural Network

The rise of machine learning has propelled deep learning into the global spotlight due to its remarkable accuracy and its ability to extract meaningful features from vast datasets. However, when applied to Hyperspectral Imaging (HSI), the process of learning and feature extraction becomes notably time-consuming. **Fig 3** illustrates the advancement of deep learning algorithms in the realm of HSI classification.

The journey of HSI classification in the literature commenced with a significant breakthrough in 1994 [24], introducing orthogonal subspace projection techniques. Subsequently, posterior to this milestone, the least squares orthogonal subspace projection approach was employed for HSI signature extraction and classification [25]. Throughout the first decades of the 21st century, various methods, including Long Short-Term Memory (LSTM) [26], K-Nearest Neighbors (KNN), Bayes, Decision Trees, and Random Forests, made their appearances.

Notably, Support Vector Machines (SVM) [27], kernel-based approaches [29], and Random Forests [28] gained popularity for HSI classification. However, the last 8-10 years have witnessed remarkable growth in HSI classification due to the emergence of deep learning techniques [29-32]. We meticulously selected and focused

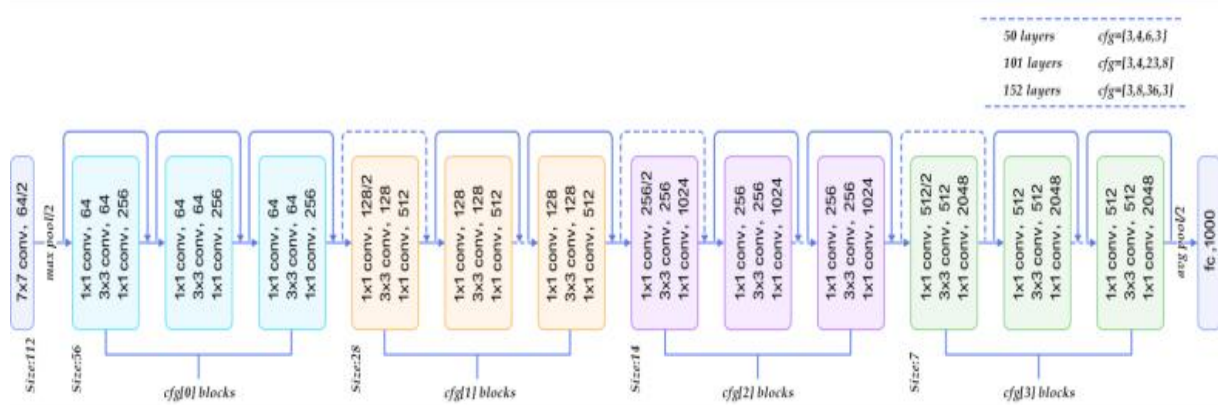


Figure 4. ResNet152 Architecture

on research with significant impact and high citation counts during this period.

Some noteworthy contributions during this surge include the implementation of Logistic Regression using Machine Learning (MLR) in a cloud environment [33], dictionary-based sparse representation [34], the adoption of deep learning [35], exploration of neural translation encoder approaches such as Gated Recurrent Units (GRU) [36], Convolutional Neural Networks (CNN) [37, 38], Deep Belief Networks [39], deep learning combined with dimension reduction [35], and the application of dictionary-based sparse representation [36].

Furthermore, techniques like Deep Recurrent Neural Networks [40], 3D deep learning frameworks [41-44], Cascaded Recurrent Neural Networks [45], and Multi-Layer Perceptrons (MLP) [46] emerged as prominent contenders in HSI classification. Hybrid approaches such as Spiking Neural Networks (SNN) [47], 1D CNN [48], Morphological Convolutional Neural Networks (MCNN) [49], S2GraphSage [50], RLSBSA [51], and 3DHyperGamo [52] models have broken previous accuracy records in predicting HSI classes.

However, a limitation persists in the use of CNN, primarily designed for square images, leaving room for innovation in the extraction of crucial features from curved and edge images. In response to this, we propose a hybrid approach involving convolutional networks for HSI feature extraction and classification.

To delve into the evolution of Convolutional Neural Networks (CNN), the first CNN, known as ConvNet, was reported in 1989. It took nearly two decades to gain widespread popularity across various domains, including computer vision, image processing, object detection, video processing, natural language processing, and speech recognition. LeNet [53] made its debut in handwritten recognition, while AlexNet [54] introduced the concept of using multiple layers of

convolution and pooling with Rectified Linear Unit (ReLU) activation for classifying 1000 classes.

ResNet [55] was a pivotal development, introducing skip connections and achieving impressive performance with lower time complexity. GoogleNet/Inception [56] improved upon the Inception module from LeNet and introduced a 22-layer deep convolutional neural network for image classification. ZDNet [57] was designed to visualize network performance statistically, tracking CNN performance through neuron activation analysis.

VGG [56] conducted extensive research into denser convolutional network design, and the Inception architecture evolved rapidly with versions V1, V2, V3, and V4 [58], focusing on reducing computational complexity. DenseNet [59,60] tackled the vanishing gradient problem by implementing cross-layer connections, similar to ResNet. Channel Boosted CNN [61] increased input channel numbers to enhance network representation capacity. RANN [62] incorporated an attention module into CNN, stacking residual blocks to identify object characteristics.

The evolution of CNN, as depicted in **Fig 4**, showcases the consistent improvements in feature extraction and classification performance. In our research, we adopted the ResNet152 model, a widely used CNN version with proven effectiveness across various vision-related applications.

ResNet152 was named and suggested to consist of 152 layers. ResNet shows a decrease in error rate with an increase in layers. ResNet152 uses the residual blocks with skip network, thus solving gradient decent problem and enhancing network performance. **Fig 4** shows the architecture of the ResNet152 model. All skip connections and layers are shown in the figure.

C. Graph convolutional network

A Graph-based convolution Network (GCN) can hold the correlated structure of HSI. It can be treated as semi-supervised learning on the graph data structure. It is capable of describing the one in non-Euclidean space. GCN architecture can preserve spectral information through localized first-order approximation. Hidden layers of GCN help encode and learn graph edges and nodes' local features. These spectral signatures of HSI are represented as an undirected graph. Let the undirected Graph is denoted as $G = (V, E)$. Where V represents vertex and E indicates edge sets, respectively. In HSI, pixels represent vertex sets, and the relation between these pixels are edges, i.e., edges represent similarities between two vertices v_i and v_j . Let F^i denote the feature vector of the vertex v_i for S layers can be evaluated using (1)

$$F_i^S = \beta \left(\sum_{v_j \in L(v_i)} K \left(w + H \left(\frac{F^j}{L(v_i) + L(v_j)} \right) \right) \right) \quad (1)$$

Where β represents the activation function (ReLU, ELU, Tanh), $W \in R$ is the weight matrix, and $L(\cdot)$ represents neighbors of a vertex. $H(\cdot)$ is a simple neural network. $K(\cdot)$ is another MLP to project the added vector into another dimension. Now to evaluate the weighted coefficient between the neighbors v_i and v_j , the edge e_{ij} is evaluated using (2)

$$e_{ij} = T \left(\frac{\exp \left(\frac{\alpha \|v_i - v_j\|^2}{\sigma^2} \right)}{\sum_{v_j \in L(v_i)} \exp \left(\frac{\alpha \|v_i - v_j\|^2}{\sigma^2} \right)} \right) \quad (2)$$

Where σ is the parameter to control the width of radial function, v_i and v_j are the spectral signatures associated with the pixel. α represents the empirical set [0.2, 0.8] to assign weights for distance and direction relations between adjacent regions. $T(\cdot)$ is a simple neural network. The information related to equation (2) and $N = |V| \subseteq \mathfrak{R}$ as an aggregated message for all nodes can be evaluated using (3)

$$Y = e \times N \times W \quad (3)$$

Stacking in GNN will help to refine the search result and produce contextual similar feature. Following **Fig 5** shows the concept of GNN, the input to GNN is node feature $X \in R^{N \times D}$, the output is the intermediate node embedding $F^1 \in R^{N \times d_1}$, where d_1 is the first embedding dimension. F^1 is made up of $F_i^1 \in R^{d_1}$. F^1 is considered to be the input to second layer and similar set of evolution is done with the d_2 dimension. After few layer at the output of the S layer is $F^S \in R^{N \times d_s}$.

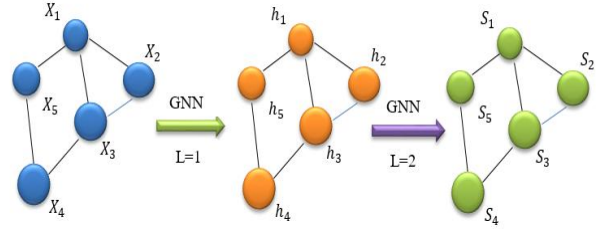


Figure 5. Layers Graph CNN

D. 3D-DWT

As we know, single HS images consist of multiple narrow bands that enable the development of algorithms to extract diverse features [65]. 3D-discrete wavelet transform (3D-DWT) can be used to decompose the image into spectral components. Later this spectral component can be directly fed into GCN for gaining spectral features. Wavelet transform is mostly used in noise removal and image compression. In general, a wavelet transform (WT) can define as (4)

$$W_f(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) \phi \left(\frac{t-b}{a} \right) dt \quad (4)$$

where a and b represent scaling and shifting parameter simultaneously used for giving frequency and time information of input signal. $\phi(t)$ is the kernel function. DWT can be defined using (5).

$$W_{p,q}^\psi(x) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) a_0^{\frac{-p}{2}} \phi \left(\frac{t-nb_0a_0^p}{a_0} \right) dt \quad (5)$$

where a_0 is scaling parameter and, b_0 is shifting parameter. Now signal $x(t)$ can be recovered by wavelet and scaling function $\phi(t)$ and $\psi(t)$. Now, equation (5) can be re-written for discrete signal $x(n)$ as (6)

$$x(n) = \frac{1}{\sqrt{M}} \sum_d C_\psi[i_0, d] \psi_{i_0, d}[n] + \frac{1}{\sqrt{M}} \sum_{i_0} \sum_d D_\phi[i, d] \phi_{i_0, d}[n] \quad (6)$$

where $x(n)$, $\psi_{i_0, d}[n]$ and $\phi_{i_0, d}[n]$ are discrete set functions. This function may vary in the range of $[0, M - 1]$ for M different points. The inner product $C_\psi[i_0, d]$ and $D_\phi[i, d]$ can be obtained from (7) and (8).

$$C_\psi[i_0, d] = \frac{1}{\sqrt{M}} \sum_n x(n) \psi_{i_0, d}[n] \quad (7)$$

$$D_\phi[i, d] = \frac{1}{\sqrt{M}} \sum_n x(n) \phi_{i_0, d}[n] \quad (8)$$

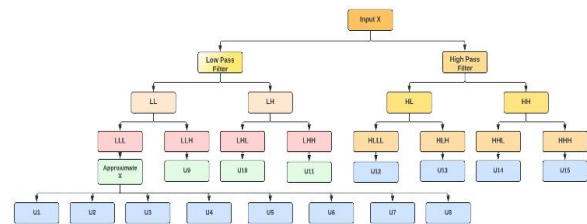


Figure 6. 3D-DWT Architecture

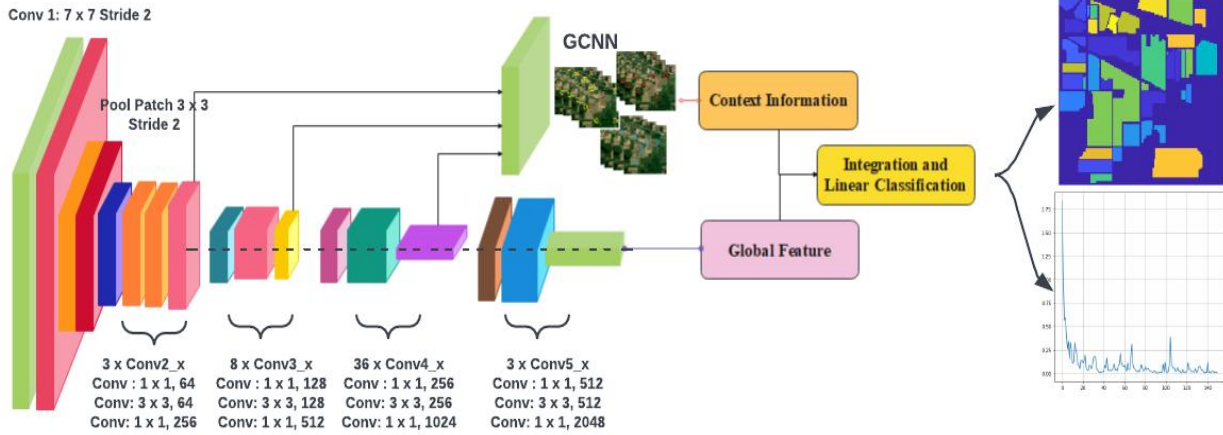


Figure 7. GCNN-RESNET152 Proposed Frame Work for HS Image

In the proposed work, 3d-DWT transformation is using expression (5) over different 1-D DWTs. Haar wavelet is used with different filter bank (L, H) with coefficient $l(d) = \left(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}\right)$ and $h(d) = \left(\frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}}\right)$. 3D-DWT over HS imaging is performed on each 1-D on HS hypercube. The tensor product is constructed for 3D-DWT using (9) and (10).

$$X^{(x,y,z)} = (L^x \oplus H^x) \otimes (L^y \oplus H^y) \otimes (L^z \oplus H^z) \quad (9)$$

$$X^{(x,y,z)} = L^x L^y L^z \oplus L^x L^y H^z \oplus L^x H^y L^z \oplus L^x H^y H^z \oplus H^x L^y L^z \oplus H^x L^y H^z \oplus H^x H^y L^z \oplus H^x H^y H^z \quad (10)$$

where \oplus represent direct sum and \otimes is product of tensor. Fig 6, shows the eight-sub band decomposition of 3D data. The sub-band can be represented using (11)

$$x_{ij} = (U_1(i,j), (U_2(i,j)), (U_3(i,j)), \dots, (U_{15}(i,j))) \quad (11)$$

3. HYBRID CONVOLUTION NETWORK

HSI contains process information from the electromagnetic spectrum. HS Image is in the form of a hypercube where each pixel spectrum of a narrow wavelength band is stored in 3D space. The spatial information is held over the x and y axis, whereas spectral information is stored on the z-axis. The image is in the form of a 3D (x, y, λ) . HSI image analysis is processing the hypercube and extracting local and global features. The exploration of spectral bands from global visual features and local contextual information can be the solution to perfectly identifying the patches in HSI images with overlapping boundaries and edges. In this view, we propose a Hybrid Convolution Network to explore the discriminative ability of the pre-trained ResNet152 model. As shown in Fig 7, the GCNN-RESNET152 consists of two synthesized; the spectral band global features and local contextual as FC features. In Fig 7, we provide a visual representation of our proposed GCNN-RESNET152 model. This Fig illustrates how the spectral

band global features and local contextual features are synthesized within the network. By doing so, we aim to improve the accuracy of identifying patches in HSI images, especially those with complex overlapping boundaries and edges. This innovative approach has the potential to advance various applications reliant on HSI data, offering more precise material and object identification.

The novelty of our work lies in its approach of combining deep learning, particularly GCNNs-RESNET152, with HSI to address longstanding challenges in feature extraction and classification. Our innovative hybrid model, which combines elements of both CNN and

GCN, addresses some of the limitations associated with traditional CNN models. By leveraging global and context features effectively, we achieve remarkable classification results, particularly with the Extreme Machine Learning classifier, surpassing the performance of other cutting-edge algorithms on benchmark datasets. This demonstrates the promise of our approach in advancing hyperspectral image classification and its potential applications in various domains. This innovative approach has the potential to enhance the accuracy and applicability of HSI across a range of domains, ultimately contributing to more informed decision-making and discoveries Authors and Affiliations

4. HYBRID CONVOLUTION NETWORK

A. DataDescription

For quantitative and qualitative evolution of proposed model experiments is conducted over four benchmark datasets.

1. The Indian Pines (IP) Dataset was obtained using the Airborne Visible/Infrared Imaging Spectrometer



(AVIRIS) from a ground distance of 20 meters. It comprises 220 spectral bands and has an image size of 145x145 pixels, with a spectral resolution of 10nm. This dataset encompasses 16 distinct land-cover categories. For our analysis, we divided the dataset into 695 samples for training and 9671 samples for testing.

2. The Pavia University (PU) Dataset was collected using the Reflective Optics System Imaging Spectrometer (ROSIS) sensor. It consists of an image with dimensions 610x340 pixels and encompasses 103 spectral bands spanning the range from 430nm to 860nm. This dataset is categorized into 9 different land-cover classes, and additional details can be found in Table II.
3. The Houston2013 (HU) dataset was captured using the ITRES CASI-1500 sensor. It features an image size of 349x1905 pixels with a spectral resolution of 10nm. The dataset comprises 144 spectral bands spanning the range from 364nm to 1046nm. Detailed information regarding the land-cover categories within the Houston dataset, which total 15, is provided in Table III.
4. The Kennedy Space Center (KSC) dataset was acquired using an AVIRIS sensor, covering a wide wavelength range from 400nm to 2500nm. The image has dimensions of 512x614 pixels and includes 176 spectral bands. This dataset encompasses 13 distinct categories related to wetlands, totaling 5202 labeled samples, as outlined in Table IV.

B. Experimental Setup

ResNet152 is implemented using the Tensor Flow platform, and Adam [63] is used for optimization. The current learning rate is dynamically updated by multiplying the base learning rate by 0.5 at an interval of every 10 epochs. The maximum number of epochs is set to 100. Batch-wise normalization [64] is used with a momentum of 0.6 and batch size 64. Training of network is done with 10-fold cross-validation. The accuracy of the result is measured using indices Overall Accuracy (OA), Average Accuracy (AA), Kappa Coefficient(κ).

TABLE I: INDIAN PINES DATASET LAND COVER 16 CATEGORIES DISTRIBUTED OVER TRAINING AND TESTING SAMPLES.

Category	Training Testing
Corn Notil	50, 1384
Corn Mintil	50-784
Corn	50-184
Grass Pasture	50-447
Grass Trees	50-697
Hay Windrowed	50-439
Soybean Notil	50-918
Soybean Mintill	50-2418
Soybean Clean	50-564
Wheat	50-162
Woods	50-1244

Buildings Grass Trees Drives	50-330
Stone Steel Towers	50-45
Alfalfa	15-39
Grass Pasture Mowed	15-11
Oats	15-5
Total	695-9671

TABLE II: PAVIA UNIVERSITY DATASET LAND COVER 9 CATEGORIES DISTRIBUTED OVER TRAINING AND TESTING SAMPLES.

Category	Training-Testing
Asphalt	584-6304
Meadows	540-18146
Gravel	392-1815
Trees	524-2912
Metal Sheets	265-1113
Bare Soil	532-4572
Bitumen	375-981
Bricks	514-3364
Shadows	231-795
Total	3921-40002

TABLE III: HOUSTON2013 DATASET LAND COVER 15 CATEGORIES DISTRIBUTED OVER TRAINING AND TESTING SAMPLES.

Category	Training-Testing
Healthy Grass	198-1053
Stressed Grass	190-1064
Synthetic Grass	192-505
Tree	188-1056
Soil	186-1056
Water	182-143
Residential	196-1072
Commercial	191-1053
Road	193-1059
Highway	191-1036
Railway	181-1054
Parking Lot1	192-1041
Parking Lot2	184-285
Tennis Court	181-247
Running Track	187-473
Total	2832-12197

TABLE IV: KENNEDY SPACE CENTRE DATASET LAND COVER 13 CATEGORIES DISTRIBUTED OVER TRAINING AND TESTING SAMPLES.

Category	Training Testing
CP Hammock	25-231
Hardwood	22-207
Spartina Marsh	50-470
Mud Flats	50-453
Scrub	70-691
Slash Pine	25-227
Swap	20-85
Cattail Marsh	40-364
Water	90-837
Willow Swamp	25-218
Oak / Broadleaf	20-141
Graminoid Marsh	40-391
Salt Marsh	40-379
Total	517-4694

C. Multilayer feature extraction

ResNet152 is a deep learning model comprising convolutional, pooling, activation, and fully connected (FC) layers. During feature extraction, the FC layer,

although losing some spatial information, serves as a global representation for classification purposes. ResNet152 is structured with four convolution layers, namely convs2_x, conv3_x, conv4_x, and conv5_x, each with different dimensional sizes (256, 512, 1024, and 2048 real numbers).

To capture the spectral structure of Hyperspectral Imaging (HSI) images effectively, we employ a graph-based convolutional network. Additionally, we utilize a 3D wavelet transform over the HSI hypercube, preserving both spatial and spectral information. The coefficients obtained from the 3D-DWT process are extracted at multiple levels. Specifically, the LLL sub-bands capture spatial information in the second-level 3D-DWT, while the LLH band retains spectral information from the HSI data. These sub-band knowledge representations are concatenated, resulting in a 3D data cube correlation.

In Fig 8, we illustrate the output of the 3D-DWT approximation and detail levels from 1 to 3, covering slices 1 to 25. This Fig provides a visual representation of the 3D-DWT wavelet decomposition, utilizing a near-symmetric wavelet.

Furthermore, in Fig 9, we demonstrate the refinement of convolutional features transformed by the 3D-DWT, showing the impact of our proposed Graph Convolutional Neural Network (GCNN) on the HSI data. This refinement step enhances the effectiveness of feature extraction and classification within the HSI dataset.

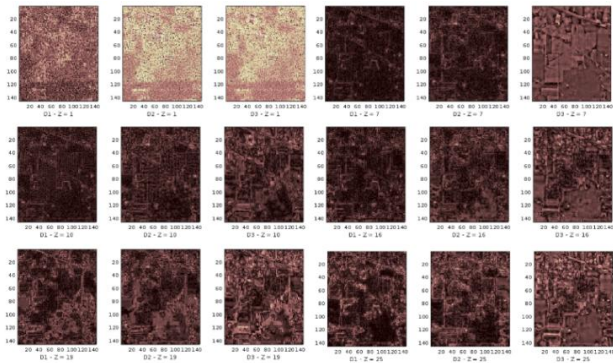


Figure 8. 3D-DWT approximation and details at level 1 to 3 for slice 1 to 25 for the Indian pine dataset

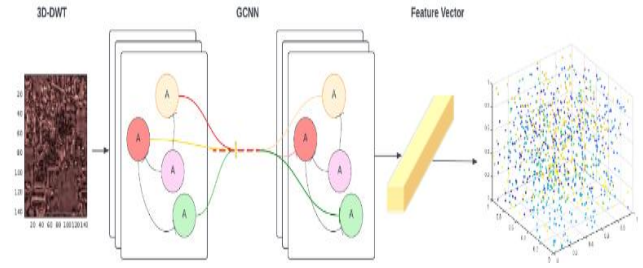


Figure 9. Refining of 3D-DWT transformed convolution feature by GCNN

D. Feature Fusion

Since the proposed approach uses two deep learning approaches for feature extraction, an effective fusion strategy is required to fuse to obtain discriminative features. FC_GCNN treated contextual information, and FC_ResNet152 held global information. The weighted concatenation method is adopted for integration for the proposed Hybrid DWT-based GCNN and ResNet152 model. The final feature can be acquired using (12).

$$F_{final} = [F_{GCNN}, \gamma FC_{ResNet152}] \quad (12)$$

Now, F_{final} can be used for training and testing a linear classifier.

E. Result Analysis

The proposed method's performance is evaluated using indices OA , AA , and κ . OA is the percentage of number of samples correctly classified N_C over available sample N_A . AA is the average of classification accuracy for all class level, and Kappa coefficient (κ) is the ratio between producer's accuracy for classification result.

$$OA = \frac{N_C}{N_A} \times 100 \% \quad (13)$$

$$AA = \frac{1}{Cl} \sum_{m=1}^{Cl} \frac{N_C^m}{N_{All}^m} \times 100 \% \quad (14)$$

$$Kappa = \frac{OA - P_e}{1 - P_e} \times 100\% \quad (15)$$

The final integrated features F_{final} is fed into a set of linear classification SVM, KNN, DT, Naïve Bayes, and extreme machine learning EML. Fig 10 compares each classifier's accuracy over OA , AA , and κ . It can be seen that the performance of EML is better than other classifiers. The OA accuracy achieved by EML is 94.4 ± 1.30 , 92.31 ± 1.78 , 97.48 ± 2.15 , and 97.7 ± 0.58 for four datasets IP, HU, KSC, and PU dataset, which is 3 to 5% better than OA achieved using SVM, NB, KNN, and DT. Similar performance is measured for AA and κ for all the five classifiers, and EML has better than the rest. Since the performance of the model solely depends upon the quality of matrix e_{ij} eq(2), which is influenced by two parameters: the number of neighbour K and σ as width of radial function. We have shown the

changing trends in two parameters and their contribution. **Fig 11** shows the OA achieved through the different combinations of these two parameters. Tables V-VIII quantitatively report the classification scores obtained by different methods in terms of OA, AA, and κ , as well as the individual class accuracies for the Indian Pines, Pavia University, and Houston2013 data sets, respectively. Comparison is only listed with the state of art methods, which they claimed to be superior in comparison to traditional classifiers. Hence, we have not tested our model with a traditional classifier. The comparison is made with random forest [28], MLR [33], SVM [27], MLP [46], RNN [70], LSTM [26], GRU [36], CNN-1D [48], CNN-2D [37], CNN-3D [43], MorphCNN [49], RLSBSA [51], 3DHyperGamo [52] and S2GraphSage [50]. The obtained accuracies for disjoint training and test samples are shown in Tables V-VIII and **Fig 12, 13, 14, and 15**.

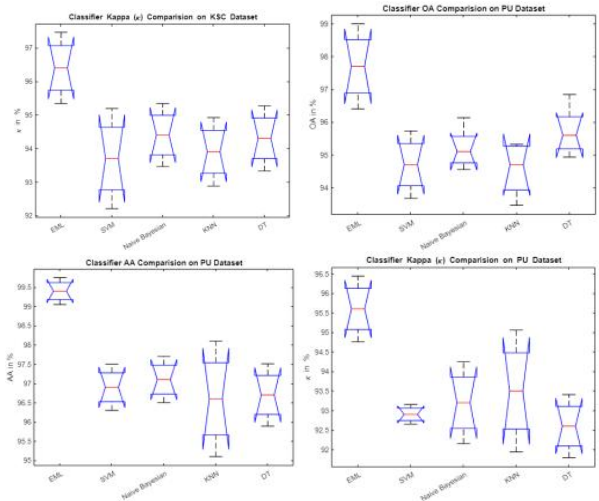


Figure 10. Accuracy Comparison in terms of OA, AA and κ in % with EML, SVM, Naïve Bayes, KNN and DT classifier for all the four datasets.

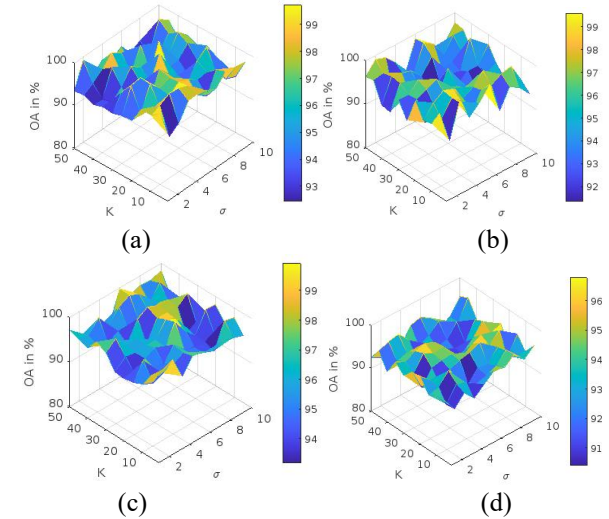
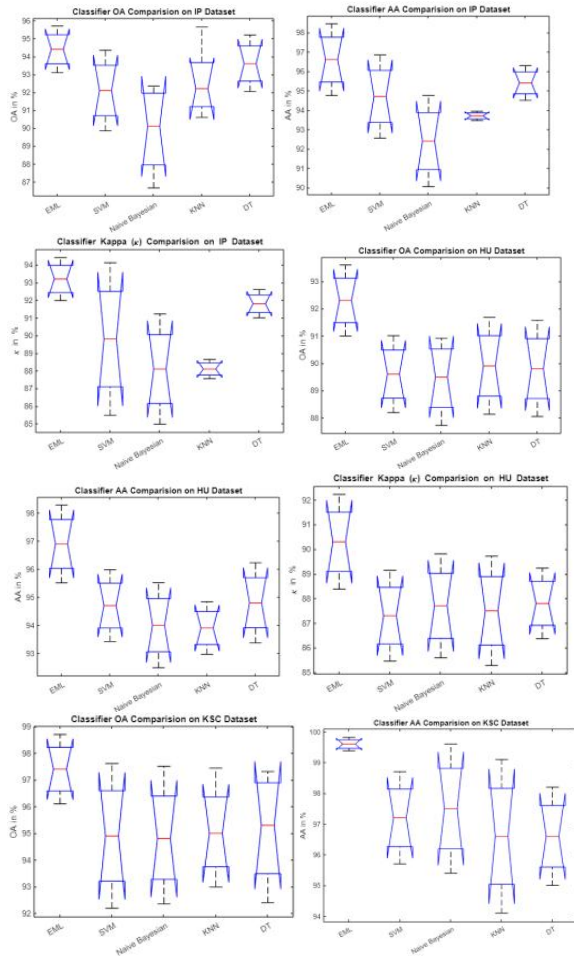


Figure 11. Parameter analysis of σ and κ for OA on datasets a) IP b) KSC c) PU, and d) HU

For the dataset Pavia University, the result of the proposed methodology shows the highest overall average and kappa accuracies which are 94.4%, 96.6%, and 93.2%, respectively. Similarly, the test accuracy on the KSC dataset achieved is 97.48%, 99.68%, and 96.43% overall, average kappa accuracy. The test result for the other two datasets is also superior to state-of-art algorithms.

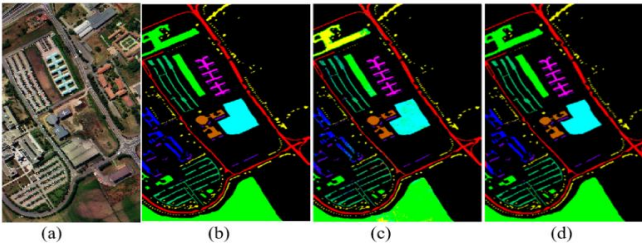


Figure 12. Classification Map on Pavia University dataset a) Original RGB Image b) Ground Truth c) ResNet152 d) Proposed hybrid GCNN-RESNET152

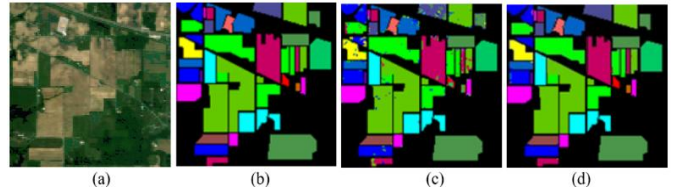


Figure 13. Classification Map on Indian Pine dataset a) Original RGB Image b) Ground Truth c) ResNet152 d) Proposed hybrid GCNN-RESNET152



TABLE V: Indian Pine quantitative comparison in terms of OA, AA, AND κ with state-of-art algorithms.

Class	RF	MLR	SVM	MLP	RNN	LSTM	GRU	CNN-ID	CNN-2D	CNN-3D	Hybrid SN	Morph CNN	RLS BS-A	3-D Hyper_Gamo	s2 Grap hSage	Proposed GCNN-RESNET 152
1	89.98	77.68	82.23	84.53	83.08	82.63	77.25	87.18	93.4	85.66	89.74	94.52	99.8	97.4	84.87	99.9
2	74.39	58.79	65.81	75.13	67.9	78.74	80.1	89.64	96.84	95.88	81.78	97.12	99.9	99.49	95.29	100.0
3	38.42	67.21	66.72	68.37	65.17	60.73	54.79	71.1	65.48	68.11	82.88	85.08	98.6	91.71	85.96	98.6
4	98.24	74.27	97.77	93.5	90.72	97.1	92.05	95.32	95.55	97.02	83.66	97	99.4	71.31	83.63	100.0
5	95.98	98.88	99.37	99.37	99.23	99.28	99.51	99.48	98.03	98.9	99.94	99.25	99.9	98.3	99.52	100.0
6	51.43	93.53	91.62	89.94	85.07	65.94	74.86	88.28	80.52	68.85	72.43	93.92	100	97.99	85.85	100.0
7	80.63	85.08	87.36	87.2	82.94	84.95	90.17	86.77	89.29	73.09	96.16	84.98	98.4	97.25	96.78	98.4
8	97.64	87.58	90.46	90.37	85.85	88.89	90.42	90.43	94.5	95.21	92.8	96.62	99.5	94.1	94.16	100.0
9	94.92	99.22	93.71	98.44	94.52	98.29	93.51	97.33	95.8	93.54	94.04	97.05	99.3	92.09	97.67	100.0
OA	77.44	72.23	77.8	82.05	77.07	80.38	80.7	89.09	92.55	89.43	84.18	95.51	99.7	93.9	91.41	97.7
AA	80.18	82.47	86.12	87.43	83.83	84.06	83.63	89.5	89.94	86.25	88.16	93.95	99.4	93.29	91.53	99.4
$\kappa(x100)$	70.44	65.44	72.06	76.89	70.84	74.32	74.76	85.5	89.9	85.61	79.13	93.95	99.6	91.86	88.61	95

Table VI: Kennedy Space centre (KSC) quantitative comparison in terms of OA, AA, AND κ with state-of-art algorithms.

Class	RF	MLR	SVM	MLP	RNN	LSTM	GRU	CNN-ID	CNN-2D	CNN-3D	Hybrid SN	Morph CNN	3-D Hyper_Gamo	s2 Grap hSage	Proposed GCNN-RESNET 152
1	99.69	100.0	94.13	99.18	87.33	92.22	89.44	99.79	85.52	97.17	100.0	97.63	97.33	99.7	100.0
2	98.38	99.03	0.0±0	86.63	63.12	81.64	70.85	99.19	67.31	92.91	100.0	86.79	71.68	98.99	100.0
3	99.23	99.54	54.59	84.25	69.72	75.38	78.89	95.11	60.09	81.04	99.69	98.31	88.84	99.37	100.0
4	88.16	99.06	17.28	78.97	47.82	58.09	44.08	77.73	45.17	44.54	99.53	88.94	89.9	78.26	100.0
5	73.72	100.0	0	13.38	68.37	74.21	65.21	80.53	67.40	85.15	98.78	48.66	82.99	83.05	99.28
6	88.88	100.0	0	78.12	56.24	65.12	59.82	91.97	65.47	62.74	100.0	86.32	77.82	80.8	100.0
7	100.0	89.88	0	78.65	83.52	90.26	89.14	95.13	77.15	80.52	97.75	97.75	99.74	99.44	98.32
8	85.51	100.0	60.10	89.62	65.57	71.40	69.76	97.45	64.75	71.49	99.90	70.76	99.58	98.53	100.0
9	96.68	100.0	89.37	97.59	88.39	90.72	86.72	99.92	89.22	98.94	100.0	91.93	94.95	100	100.0
10	99.22	100.0	98.83	96.50	92.42	88.92	88.53	99.90	73.08	90.67	100.0	100.0	99.37	96.56	100.0
11	100.0	98.03	94.94	98.50	83.89	90.26	84.83	100.0	87.55	97.56	96.34	100.0	98.85	99.64	98.33
12	97.89	99.29	89.25	98.52	81.31	87.46	83.57	98.36	82.48	99.30	99.06	97.89	98.3	94.83	100.0
13	100.0	100.0	100.0	100.0	99.88	100.0	99.92	100.0	99.92	100.0	100.0	100.0	100	99.43	100.0
OA	96.17	99.45	72.84	91.76	81.47	86.10	82.76	97.18	79.98	89.71	99.48	92.76	95.31	99.67	97.48
AA	94.41	98.83	53.73	84.61	75.96	81.97	77.75	95.00	74.24	84.77	99.31	89.61	92.26	94.51	99.68
$\kappa(x100)$	95.74	99.40	69.29	90.82	79.33	84.51	80.79	96.86	77.63	88.51	99.43	91.94	94.78	96.27	96.43

Table VII: Pavia University quantitative comparison in terms of OA, AA, AND κ with state-of-art algorithms.

Class	RF	MLR	SVM	MLP	RNN	LSTM	GRU	CNN-ID	CNN-2D	CNN-3D	Hybrid SN	Morph CNN	RLSBS-A	3-D Hyper_Gamo	s2 Grap hSage	Proposed GCNN-RESNET 152
1	89.98	77.68	82.23	84.53	83.08	82.63	77.25	87.18	93.4±	85.66	89.74	94.52	99.8	97.4	84.87	99.9
2	74.39	58.79	65.81	75.13	67.9	78.74	80.1	89.64	96.84	95.88	81.78	97.12	99.9	99.49	95.29	100.0
3	38.42	67.21	66.72	68.37	65.17	60.73	54.79	71.1	65.48	68.11	82.88	85.08	98.6	91.71	85.96	98.6
4	98.24	74.27	97.77	93.5	90.72	97.1	92.05	95.32	95.55	97.02	83.66	97	99.4	71.31	83.63	100.0
5	95.98	98.88	99.37	99.37	99.23	99.28	99.51	99.48	98.03	98.9	99.94	99.25	99.9	98.3	99.52	100.0
6	51.43	93.53	91.62	89.94	85.07	65.94	74.86	88.28	80.52	68.85	72.43	93.92	100	97.99	85.85	100.0
7	80.63	85.08	87.36	87.2	82.94	84.95	90.17	86.77	89.29	73.09	96.16	84.98	98.4	97.25	96.78	98.4
8	97.64	87.58	90.46	90.37	85.85	88.89	90.42	90.43	94.5	95.21	92.8	96.62	99.5	94.1	94.16	100.0
9	94.92	99.22	93.71	98.44	94.52	98.29	93.51	97.33	95.8	93.54	94.04	97.05	99.3	92.09	97.67	100.0
OA	77.44	72.23	77.8	82.05	77.07	80.38	80.7	89.09	92.55	89.43	84.18	95.51	99.7	93.9	91.41	97.7
AA	80.18	82.47	86.12	87.43	83.83	84.06	83.63	89.5	89.94	86.25	88.16	93.95	99.4	93.29	91.53	99.4
$\kappa(x100)$	70.44	65.44	72.06	76.89	70.84	74.32	74.76	85.5	89.9	85.61	79.13	93.95	99.6	91.86	88.61	95.6



Table VIII: Houston University quantitative comparison in terms of OA, AA, AND κ with state-of-art algorithms.

Class	RF	MLR	SVM	MLP	RNN	LSTM	GRU	CNN-ID	CNN-2D	CNN-3D	Hybrid SN	Morph CNN	RLSBS-A	3-DHyperGamo	s2Grap hSage	Proposed GCNN-RESNET152
1	82.87	82.24	82.34	81.23	82.22	82.76	82.58	82.28	82.25	82.1	82.74	82.43	94.22	82.87	82.24	82.34
2	82.51	82.5	83.36	82.29	82.87	80.19	81.64	91.78	84.15	84.14	90.91	84.42	97.23	82.51	82.5	83.36
3	64.09	99.8	99.8	99.72	99.72	99.68	99.88	99.92	90.31	77.85	98.81	97.21	60.22	64.09	99.8	99.8
4	92.04	98.3	99.96	87.58	93.5	91.23	93.22	94.36	87.24	89.24	83.96	92.37	93.86	92.04	98.3	99.96
5	99.81	97.44	99.77	97.35	97.76	97.65	97.37	98.77	99.51	98.97	99.46	99.77	100.0	99.81	97.44	99.77
6	96.27	94.11	97.9	94.55	95.1	97.06	98.32	95.8	96.43	98.91	98.60	99.16	90.20	96.27	94.11	97.9
7	86.19	73.37	77.43	75.24	81.41	78.88	77.03	82.78	86.44	85.48	75.62	88.07	95.57	86.19	73.37	77.43
8	41.69	63.82	60.3	57.0	40.06	40.11	53.62	75.51	70.03	62.06	93.16	72.09	98.46	41.69	63.82	60.3
9	86.02	70.23	76.77	75.59	76.54	81.55	79.06	81.44	79.53	80.81	81.39	84.09	92.45	86.02	70.23	76.77
10	36.00	55.6	61.29	48.78	47.44	47.37	49.54	68.71	60.22	54.75	76.51	62.86	96.21	36.00	55.6	61.29
11	64.67	74.21	80.55	76.25	76.24	76.38	80.82	85.24	82.93	66.78	89.21	89.15	94.34	64.67	74.21	80.55
12	67.27	70.41	79.92	75.31	76.33	79.98	84.15	89.93	92.87	93.83	96.28	93.02	97.38	67.27	70.41	79.92
13	89.23	67.72	70.88	73.18	69.12	71.37	72.63	74.88	86.21	82.34	86.78	89.61	95.25	89.23	67.72	70.88
14	100.0	98.79	100.0	99.84	100.0	99.11	99.92	99.68	98.92	96.31	100.0	99.19	100.0	100.0	98.79	100.0
15	90.06	95.56	96.41	97.8	97.59	98.14	98.22	98.48	77.63	75.85	100.0	97.04	100.0	90.06	95.56	96.41
OA	75.38	78.97	81.86	78.22	77.95	78.16	80.21	86.42	83.27	80.24	88.31	86.51	92.31	75.38	78.97	81.86
AA	78.58	81.63	84.31	81.45	81.06	81.43	83.2	87.97	84.98	81.96	90.23	88.78	96.9	78.58	81.63	84.31
$\kappa(x100)$	73.49	77.3	80.43	76.55	76.23	76.52	78.66	85.27	81.89	78.62	87.33	85.4	90.33	73.49	77.3	80.43

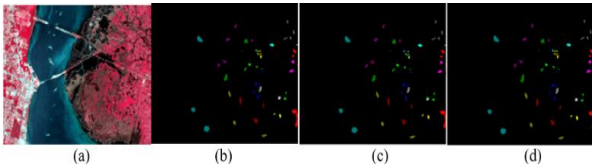


Figure 14. Classification Map on KSC dataset a) Original RGB Image b) Ground Truth c) ResNet152 d) Proposed hybrid GCNN-RESNET152

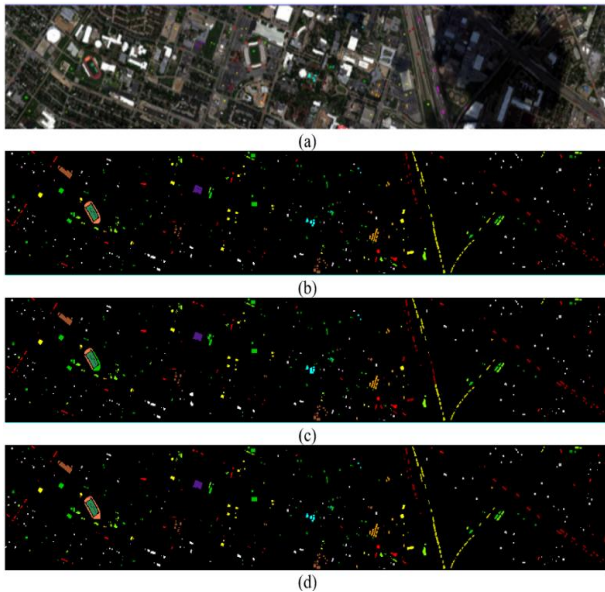


Figure 15. Classification Map on Houston dataset a) Original RGB Image b) Ground Truth c) ResNet152 d) Proposed hybrid GCNN-RESNET152

An effort is made to show the visual comparison (Fig 12-15) between ResNet152 and the proposed model in the form of classification maps. In general, ResNet152 pixel-wise classification models result in noise in the classification maps. The proposed approach of using discrete wavelet transform and implementing GCNN for batch-wise feature fused with ResNet152 elements can preserve global and local information, thus resulting in better visibility and classification accuracy.

5. NOVELTY & SUMMARIZATION

The novelty of our work lies in the development and application of a hybrid feature extraction and classification model, GCNN-RESNET152, for hyperspectral image (HSI) classification. This approach combines the strengths of two distinct techniques, ResNet152 and Graph Convolutional Network (GCN), to achieve superior results in HSI classification.

- Global Feature Extraction with ResNet152: Our work begins by employing the ResNet152 model, a well-established deep learning architecture, for global feature extraction from hyperspectral images. While ResNet models are commonly used in image classification tasks, their application in hyperspectral imagery is relatively novel. This initial step allows our model to capture high-level information from the



HSI data, which is crucial for accurate classification. By adapting ResNet152 for this specific domain, we bring a fresh perspective to hyperspectral image analysis.

- **Context Feature Extraction with GCN:** The second unique aspect of our work involves the use of the Graph Convolutional Network (GCN) to extract context features from the 3D discrete wavelet transform image. GCN is typically employed in graph-based data, and its application to hyperspectral imagery is a novel and innovative approach. By doing so, we enable our model to capture intricate topological and geometric features present in geospatial images. This capability is essential for precise classification, especially in scenarios where the spatial context plays a critical role. The adaptation of GCN for hyperspectral image analysis represents a significant advancement in the field.
- **Integration of Extracted Features:** The integration of both global features from ResNet152 and context features from GCN using weighted methods is another novel aspect of our work. This fusion of information is a key innovation, as it allows our model to leverage the strengths of both feature extraction processes. By combining these features, we enhance the model's overall classification performance. This integrated approach to feature extraction and fusion represents a unique contribution to the HSI classification literature.
- **Classification with Various Linear Classifiers:** In our work, we explore various linear classifiers, including Support Vector Machine, Decision Tree, Naïve Bayes, K-Nearest Neighbors (KNN), and Extreme Machine Learning, for the classification task. While these classifiers are not novel in themselves, our application of them within the context of our hybrid feature extraction framework is innovative. We systematically evaluate these classifiers to determine their effectiveness in utilizing the integrated features from our model.
- **Superior Performance of Extreme Machine Learning (ELM):** One of the most striking findings from our experiments is the consistent outperformance of the Extreme Machine Learning (ELM) classifier in terms of classification accuracy. This result underscores the effectiveness of our proposed hybrid model in providing discriminative features for accurate HSI classification. The preference for ELM among a range of classifiers highlights a unique and powerful aspect of our approach.

In summary, our work introduces several novel elements to the field of hyperspectral image classification. From the adaptation of ResNet152 and GCN for feature extraction to the integration of these features and the preference for Extreme Machine Learning as the

classifier, each component contributes to the innovation of our approach. Our research not only advances the state-of-the-art in HSI classification but also offers new perspectives and methodologies that can potentially benefit other image analysis domains. The combination of these novel elements makes our work a significant contribution to the field of hyperspectral image analysis.

6. CONCLUSION

To preserve the context information of the pixels, the graph structure can characterize the HS image data structure in 3D space. The noise can be filtered using 3D-DWT for retrieving smoothing features. The HS Image is trained in batches, thus achieving flexible lower computational cost. Our approach of combining the global and contextual features uses GCNN and ResNet152 to reach diverse and discriminative features representation of HSI. These Features are classified using a different set of classifiers. Accuracy archived of Extreme machine learning has reported maximum accuracy in terms of overall, average, and kappa accuracy. We have used the weighted concatenation method adopted for the integration of features. Our experiment is conducted on four different HSI datasets. The result successfully proves the superiority of the proposed model over all other state-of-art algorithms.

In the future, we would like investigate different possible combinations with an advanced fusion strategy to exploit the spectral information of HSI. The success of deep learning models often relies on meticulous hyper parameter tuning, including learning rates, batch sizes, and architectural choices. Failing to find the optimal set of hyper parameters can lead to suboptimal performance. In future work will also focus on designing optimization techniques for parameter tuning. Some other limitation is data dependency, where model's performance is highly dependent on the quality and representativeness of the training dataset. It may not generalize well to new or unseen datasets, which is a common challenge in machine learning. To come over this we would like to check model performance over another dataset also.

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