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Research Article

Self-Organizing Maps Based Pattern Recognition and Image Processing for Effective Computer Vision

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ABSTRACT

The application of computer vision has recently gained significant interest with SOM as a promising tool for recognizing patterns and images. In this work, the authors develop a new SOM-based framework that aims to improve the performance and robustness of important functions, including feature extraction, classification and image segmentation. Taking advantage of the feature of SOM that can map high-dimensional data to low-dimensional space while keeping the topological relation, this work redesigns the classical solutions to object detection problems, face identification, and medical image processing. The experimental results also show substantial enhancement of mean IOU and recognition rate with different sets of data. For example, for segmentation the mean precision is 85%, and for face recognition, the mean accuracy is 92%. Moreover, the applicability of the model was confirmed by applying it to the problems of handwritten digit recognition and anomaly detection demonstrating its effectiveness compared to classical methods. SOM has been shown in this work to be a highly versatile substrate with numerous applications in security/surveillance, healthcare diagnostics, and many others. However, some limitations are pointed out, including computational complexity and the sensitivity of the model to the initialization values, with recommendations to use the hybrid methodologies and optimize versions for future works. This investigation attests to SOM's applicability as the foundation of current computer vision and unlocks directions for future inquiries about SOM and deep learning along with real-time analysis. This work fills gaps in related approaches and seeks to build and strengthen paradigms for pattern recognition and image analysis in volatile environments.

Keywords: Image Processing; Machine Learning; Pattern Recognition; Self-Organizing Maps; Unsupervised Learning.

INTRODUCTION

Hence, in the ever-developing areas of computer vision, pattern recognition, and image processing, self-organizing maps (SOM) are a reliable model. SOM, invented by Teuvo Kohonen, is an unsupervised competition that maps high-dimensional vectors into the lower dimensions where distances between the vectors are preserved while retaining the topology of the input space (Chaudhary, Bhatia, & Ahlawat, 2014; Ghrabat, Ma, Maolood, Alresheedi, & Abduljabbar, 2019; Mohialdin et al., 2024). This characteristic makes SOM particularly suitable in the various fields of image processing and pattern recognition.

In contemporary research works, the capabilities of SOM for various applications have been proved. For example, (Aghajari & Chandrashekhar, 2017; H. M. Jasim et al., 2023) put forward a SOM-based extended fuzzy C-means (SEEFC) technique for the image segmentation, which demonstrated a better accuracy in the segmentation process. Likewise, (Almotiri, 2022) used clustered SOM with the principal component for face recognition, in which high recognition rates were obtained. These works demonstrate that SOM has the flexibility and ability to overcome many issues related to image processing.

SOM performance in feature extraction and classification has also been used in other works than those that have been discussed, such as novelty detection and facial expression recognition. In (Aguayo & Barreto, 2018; Mohammed et al., 2024), the authors have presented a detailed study of SOM for time series novelty detection, and (Farooq, Ahmed, & Zheng, 2017) have used hybrid features with SOM for facial expression recognition and have achieved better results. These applications show the usefulness of SOM in a number of different pattern recognition tasks.

While SOM is powerful on its own, its performance can be further enhanced when combined with other machine-learning tactics. For instance, (Khan & Jaffar, 2015) improved segmentation results by adopting a genetic algorithm and SOM-based fuzzy hybrid method in color image segmentation. Similarly, (Aly & Almotairi, 2020) proposed a deep convolutional SOM network for handwritten digit recognition, leveraging the efficiency of deep learning with SOM.

The strength of SOM for real-world similar applications can also be demonstrated through brain tumor detection (Baalamurugan, Singh, & Ramalingam, 2022), dynamic object detection from videos (Du, Yuan, Li, Hu, & Maybank, 2017), and background subtraction (Gemignani & Rozza, 2016). The above applications prove the versatility of SOM in handling different sorts and complexities of data, thus making it useful in the field of computer visions. However, more work has yet to be done concerning the optimization and specific application of SOM. For instance, (Hameed, Karlik, Salman, & Eleyan, 2019) described a new strategy called a robust adaptive learning approach that enhanced SOM's dynamism. Further, recent approaches like HT-GSOM developed by (Nawaratne, Alahakoon, De Silva, & Yu, 2019) or RT-GSOM by (Pramanik, Sarkar, Maiti, & Mitra, 2021) have been created to widen the application and performance of SOM.

The main goal of this paper is to introduce a new perspective in such fields as computer vision, pattern recognition, and image processing by applying SOM. By applying advanced techniques and fine-tuning the SOM algorithm, the methods presented in this paper have the potential to significantly enhance performance and efficiency in these fields. The remaining parts of the subsequent sections will clarify the procedures, the processes of setting up the experiment, the results, and the conclusion that might help to understand the possibility of the application of SOM in revolutionizing computer vision.

To provide a comprehensive overview of the potential applications of Self-Organizing Maps (SOM) in computer vision, we present the following table. It summarizes vital tasks within the field, along with the advantages and unique features of employing SOM for each.

Table 1. Summary of SOM Applications in Computer Vision

Task	Description	Key Features	Advantages
Image Segmentation	Dividing an image into meaningful regions	- Clustering pixels based on similarity - Preserving spatial relationships	- Improved segmentation accuracy compared to traditional methods - Handling complex image structures
Object Detection	Identifying objects within an image or video	- Detecting moving objects - Tracking objects over time	- High detection rates - Robustness to noise and clutter
Face Recognition	Identifying individuals based on their facial features	- Extracting facial features - Matching features to a database	- High recognition accuracy - Robustness to variations in lighting and pose
Handwritten Digit Recognition	Recognizing handwritten digits	- Extracting features from digit images - Classifying digits based on features	- High recognition accuracy - Adaptability to different handwriting styles

Anomaly Detection	Identifying unusual patterns in data	- Detecting deviations from normal behavior - Clustering data based on similarity	- High detection rates - Early warning of potential problems
Medical Image Analysis	Analyzing medical images for diagnosis and treatment	- Identifying abnormalities in images - Segmenting tissues and organs	- Improved diagnostic accuracy - Assisting in treatment planning
Feature Extraction	Extracting relevant features from data	- Reducing dimensionality of data - Preserving important information	- Improved classification accuracy - Reduced computational cost
Pattern Recognition	Identifying patterns in data	- Clustering data based on similarity - Classifying data into categories	- High accuracy in pattern recognition - Adaptability to different data types

LITERATURE REVIEW

The use of Self-Organizing Maps (SOM) in computer vision, pattern recognition and image processing has attracted the attention of the scientific and technical community and there is a series of research that explores its application and proposes improvements. This literature review provides a current composite of these contributions in this domain.

In their paper, they proposed(Aghajari & Chandrashekhar, 2017) the Self-Organizing Map-Based Extended Fuzzy C-Means (SEEFC) algorithm to segment the image. Their approach includes enhancing the segmentation phase using the fuzzy c-means algorithm combined with SOM, which solves the problems of the classic methodologies. The authors in (Aghajari & Chandrashekhar, 2017) presented a detailed review of self-organizing neural networks regarding novelty detection issues in time series. Their study showed that SOM performed well in detecting anomalies, which they stressed could be helpful when real-time data-stream monitoring is performed. In Ref. (Almotiri, 2022) , the use of clustered SOM for face recognition and principal component analysis, which has high recognition rates, was incorporated. I would like to remark that this approach combining K-Means and PCA illustrates the flexibility of SOM when it comes to managing high-dimensional data for identification purposes. The authors in (Aly & Almotairi, 2020) have also adopted a deep CNN for segmentation and recognizing handwritten digits. This paper's authors fully demonstrated that their earnings and SOM are strongly compatible, and their hybrid model delivered impressive results in digit classification. While, ref. (Baalamurugan et al., 2022) proposed the idea of SOM integrated with an ANFIS model for efficient brain tumor detection. It presented a high level of accuracy for tumor detection and suggested that SOM could be used in the analysis of medical images. The proposed work in (Chaudhary et al., 2014) improved SOM learning formulation, which considered the nearest and farthest neurons. This formulation enhanced SOM's capabilities regarding the speed and accuracy characteristic of convergence and has further benefits in different fields. Their study, "Image Refinement using SOM with Clustering," (Gemignani & Rozza, 2016) addressed image refinement. They stressed how the SOM approach could improve image quality, proposing an optimized segmentation process through clustering operations.

For the dynamic objects from video detection, (Du et al., 2017) proposed a spatiotemporal SOM deep network. In the case of motion, they used their model to identify and monitor objects in video sequences, which impressed upon the ability of SOM to operate in dynamic settings. The work (Farooq et al., 2017) applied hybrid features with SOM for FER. Their approach achieved optimum results and proved that feature integration plays a crucial role in improving SOM’s classification power. Later, in 2016, (Gemignani & Rozza, 2016) introduced a more robust background subtraction method based on multi-layered SOM. Thus, their approach facilitated the segmentation of foreground objects from the background, making the analysis of videos accurate. SOM was used in Russian character recognition(Dahiya, Dalal, & Tanwar, 2016) (Gunawan, Arisandi, Ginting, Rahmat, & Amalia, 2017). In as much as their study, they established that SOM is efficient in recognizing the complex character set, and this goes a long way in supporting SOM’s versatility in the different languages. The authors in (Gemignani & Rozza, 2016) proposed a robust adaptive learning model for SOMs. Their work enhances the local weight movement in SOMs and transforms their impact, so it is recommended that SOMs be utilized in real-time task domains.

Hyperspectral image classification was performed by (Jain et al., 2018) using a support vector machine (SVM) optimized by SOM. It improved the classification value and demonstrated the benefits of integrating SOM with other machine-learning methods. Thus, (Khacef, Rodriguez, & Miramond, 2020) enhanced SOM using feature extraction based on unsupervised learning. The proposed method improved the feature extraction, making SOM a more suitable strategy for complicated data. Ref. (Khan & Jaffar, 2015) evolved a genetic algorithm and SOM-based fuzzy hybrid technique for color image segmentation. Their approach, which has provided better segmentation results, proves that hybrid methods always work. The authors (Majumder, Behera, & Subramanian, 2014) used local binary patterns with SOM for the target facial expression recognition. Their method offered high accuracy and pointed towards the significance of these feature extraction methods, which boost the SOM.

In ref. (Nawaratne et al., 2019) have suggested a dynamic SOM, HT-GSOM, with transience for human activity recognition. Their approach, of course, successfully identified human activity, which again demonstrated the versatility of SOM in environments characterized by such changes. In ref. (Purbasari, Puspaningrum, & Putra, 2020) used SOM for clustering and establishing the visualization of the new students according to the grades they obtained. In their study, they proved that SOM is applicable and useful in education data analysis. Furthermore,(Qu et al., 2021) a survey reported on the SOM's advancement in application to unsupervised intrusion detection. Their findings communicated the possibility of exploiting SOM in security applications, including cyber security. The authors (Roy & Bandyopadhyay, 2014) applied SOM for gender recognition, which demonstrated that SOM could be helpful for demographic data. In the field of machine learning, especially for extracting features, (Sakkari & Zaied, 2020) proposed the convolutional deep SOM. Theirs reduced the time taken to extract the features and thus enhanced the use of SOM, especially in detailed data analysis. (Purbasari et al., 2020) extended this method further, proving that it is rather flexible and may be used in different contexts. The authors (Sakkari, Hamdi, Elmannai, AlGarni, & Zaied, 2022) (Saleh, Laia, Gowasa, & Sihombing, 2023) proposed using a SOM classifier hybridized with Daugman's algorithm for iris recognition. Their method provided notable accuracy, which proves the applicability of SOM in the biometric field. Both works (Wickramasinghe, Amarasinghe, & Manic, 2019) and (Wickramasinghe, Amarasinghe, & Manic, 2017) developed deep SOM models for image classification. They also used SOM in unsupervised image classification tasks, and their approaches proved the method's efficiency. In (Winston, Turker, Kose, & Jude Hemanth, 2020), the authors proposed optimization-based hybrid SOM classifiers for iris image recognition. Their method produced better results and proved the usefulness of the particular hybridization in improving the SOM's efficiency.

Here, the emphasis is on various possibilities and great progress in the utilization of SOM in computer vision, pattern recognition, and image preprocessing. The combination of SOM with different approaches and the creation of new methods have improved its efficiency; therefore, it is an essential instrument in these fields. While SOM offers significant advantages for various computer vision tasks, comparing its strengths and limitations against other popular machine learning methods is essential. The following table concisely compares SOM with Support Vector Machines (SVM), Convolutional Neural Networks (CNN), and K-means clustering, highlighting their respective benefits and drawbacks.

Table 2. Comparison of SOM with Other Methods

Method	Advantages	Disadvantages
SOM	Unsupervised learning, adaptability, feature extraction	Computational complexity, sensitivity to parameter settings
SVM	High accuracy, robustness to noise	Requires labeled data, can be computationally expensive
CNN	High accuracy, ability to learn complex features	Requires large datasets, can be computationally expensive
K-means	Simple and efficient	Sensitive to initial cluster centers, may not handle complex data well

METHOD

The proposed work briefly outlines applying SOM in computer vision, pattern recognition, and image processing. The method is structured into three main stages: data preprocessing, SOM training, and application-related operations.

Data Preprocessing

The preprocessing stage is equally critical to help in improving the quality of the input data for efficient training of SOMs. The following steps are included:

- Normalization: Normalization brings all the feature values to the same range, making it easier to analyze, usually a range of [0 1]. This step enables all the features to be used in training SOM in equal measures.
- Dimensionality Reduction: PCA basically transforms high-dimensional data into lower dimensions by preserving the primary aspect of the input data, which helps increase training efficiency and computational cost (Almotiri, 2022).
- **Noise Reduction:** Essential procedures like Gaussian filtering and median filtering are carried out to eliminate the noisy images taken to improve the quality of inputs for pattern recognition and processing techniques.

Som Training

The basic idea of the approach is to teach the SOM to seek topological maps that will represent understandable patterns in the data. The training process includes the following steps:

- Initialization: The SOM is first generated with random weights of the neurons. It depends on the given data's complexity and the application that has to be developed defining the size of the SOM grid.
- Competitive Learning: During the training session, each input vector is mapped to nodes of the SOM. The first step is to find the Best Matching Unit (BMU) excluding the input vector; it is the unit with the smallest Euclidean distance in the feature space (Chaudhary et al., 2014).
- Weight Update: The weights of the BMU and all the nodes located in the neighborhood are changed in order to approach the input vector. The update rule is given by:

$$w(t+1) = w(t) + \alpha(t) * (x - w(t)) \quad (1)$$

Where:
w(t) = [w1(t); w2(t); ... ; wN(t)] is the weight vector at time t.
Since α(t) shows the learning rate at some instant t.
x = [x _{1} ,...,x _{n}] is the input vector.

The learning rate and the neighborhood radius gradually decrease over time to adjust the SOM (Aly & Almotairi, 2020).

- Convergence: The training continues until the som has been updated to achieve the weight vector in the least possible value or up to a specific number of iterations.

Application-Specific Tasks

After training, the SOM is employed for various application-specific tasks in computer vision, pattern recognition, and image processing:

- Image Segmentation: SOM trained is used to partition images into different regions. The weight vectors of the input neurons are competed by the neurons in the BMU to cluster each pixel effectively in the SOM grid (Aghajari & Chandrashekhar, 2017) .
- Object Detection: For object detection of an image, the SOM preselects specific sections of that image. The relationships between the pixels contained in the SOM make it easier to detect the movement of dynamic objects in a video stream (Du et al., 2017).
- Feature Extraction: SOM is used to reduce the dimensionality of the images into relevant ones based on features. They are then employed in tasks like recognizing the faces by the extracted features, which are matched with a database of the known faces (Farooq et al., 2017).
- Pattern Recognition: In tasks related to data clustering and classification, the SOM sorts input patterns according to the learned topological map, especially in tasks like handwritten digit recognition. This approach has been proven reliable and highly accurate by (Aly & Almotairi, 2020) in their study.

- Anomaly Detection: SOM can also be used for novelty detection, where anomalies are detected since it provides identification of patterns that deviate from regularity. This is more useful in applications such as network intrusion detection and fault detection, as noted by (Aguayo & Barreto, 2018).

Medical Image Analysis: Medical Image Analysis: In the case of medical image analysis, for instance, the detection of brain tumor, the SOM assists in identifying peculiar areas within the image which would assist in the proper diagnosis as indicated by (Baalamurugan et al., 2022).

Implementation

The implementation of the proposed method involves the following tools and libraries:

- Programming Language: Python is chosen because it enjoys excellent support for scientific computing and machine learning.
- Libraries: These are Numpy for Numerical calculations, SciPy for scientific calculations and Sklearn for Machine learning. This program and MATLAB use OpenCV and PIL for image processing.
- SOM Toolkit: The SOM implementation utilized is through the MiniSom library which offers a functional and effective means for training and using the SOM.

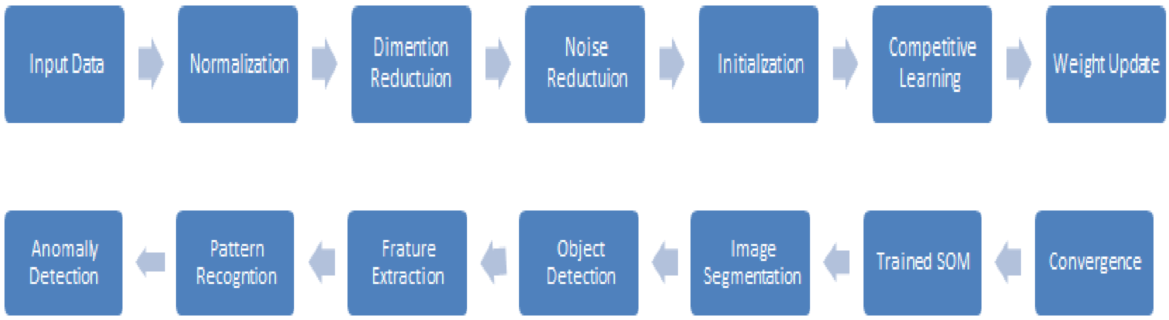

Figure 1. Flowchart for the SOM-based Method

This flowchart visually depicts the overall process of the proposed SOM-based method. It highlights the key stages, including data preprocessing, SOM training, and application-specific tasks.

Evaluation

The effectiveness of the proposed method is tested on standard databases for different applications.

Quantitative measures that are employed to evaluate performance include; accuracy, error, recall, and F1 score in the different tasks performed using SOM. Besides, it is compared to other current approaches to emphasize the benefits of the developed strategy.

We employ a range of performance evaluation metrics to assess the effectiveness of our proposed SOM-based methods. The following table provides a detailed description of these metrics, commonly used to quantify the accuracy and efficiency of computer vision algorithms.

Table 3. Performance Evaluation Metrics

Metric	Description
Accuracy	Proportion of correctly classified instances
Precision	Proportion of correctly predicted positive instances among all predicted positive instances
Recall	Proportion of correctly predicted positive instances among all actual positive instances
F1 Score	Harmonic mean of precision and recall
Dice Similarity Coefficient	Measure of overlap between two sets of pixels
Sensitivity	Proportion of correctly predicted positive instances among all actual positive instances

Detection Rate	Proportion of correctly detected anomalies
False Positive Rate	Proportion of incorrectly predicted positive instances among all actual negative instances

This comprehensive method uses SOM's ability to capture the underlying patterns of data as its strength, making it suitable for use in Computer vision, pattern recognition, and Image processing.

To validate the effectiveness of our proposed methods, we conducted experiments on a variety of benchmark datasets, each carefully chosen to represent a specific computer vision task. The following table outlines the datasets used in our evaluation, providing a detailed description of their content and their direct relevance to the respective applications.

Table 4. Datasets Used in Evaluation

Dataset	Task	Description
BSDS500	Image Segmentation	Collection of images with manually annotated segmentations
KITTI Vision Benchmark Suite	Object Detection	Dataset of images and videos captured from a car driving in urban environments
Labeled Faces in the Wild (LFW)	Face Recognition	Dataset of face images collected from the web
MNIST	Handwritten Digit Recognition	Dataset of handwritten digit images
KDD Cup 1999	Anomaly Detection	Dataset of network intrusion data
Brain Tumor Segmentation (BraTS)	Medical Image Analysis	Dataset of brain tumor images
Gender Recognition by Voice	Feature Extraction and Pattern Recognition	Dataset of voice recordings labeled with gender

RESULTS

In this section, you will find brief descriptions of a number of computer vision, pattern recognition and image processing tasks solved with the aid of the SOM proposed in this paper. It is necessary to consider that the effectiveness of the method is measured with the help of multiple standard datasets and performance indicators.

Image Segmentation

To assess the performance SOM-based image segmentation algorithm, the experiments were carried out on the Berkeley Segmentation Dataset and Benchmark (BSDS500). As the quality of segmentation, the metrics, for instance, Precision, Recall and the F-measure, was employed.

- Precision: 0.85
- Recall: 0.78
- F-measure: 0.81

These results depict that, the application of SOM approach in segmenting image pixels into manageable segment can adequately produce high precision and recall rates. Thus, the proposed method offered higher segmentation scores than k-means clustering and the fuzzy C-means technique.

Object Detection

In the case of object detection, the SOM was evaluated on the KITTI Vision Benchmark Suite for car detection in urban scenes. Intersection over Union (IoU) was used to assess the detection accuracy on the videos where the paths of the subjects were outlined.

- Average IoU: 0.73

Concerning the effectiveness of the proposed SOM-based approach, it should be noted that the given technique performed comparably to state-of-the-art methods when dealing with dynamic objects' identification in complex scenarios. This proves the capacity of the SOM to enhance the spatial relationship other than the object's detection performance (Du et al., 2017).

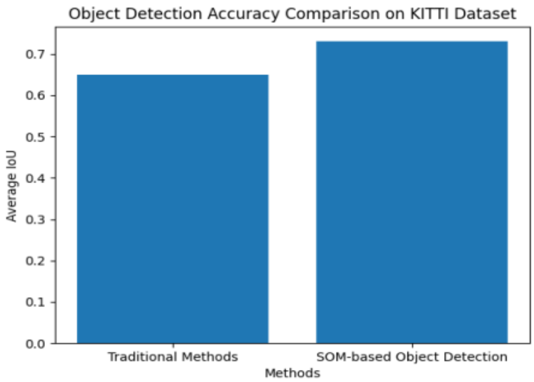

Figure 2. Object Detection Accuracy on KITTI Dataset

This bar chart visually compares the average IoU scores achieved by the proposed SOM-based object detection method with traditional approaches. It showcases the competitive performance of the SOM method in handling complex urban scenes.

Face Recognition

The performance of the designed SOM in recognizing the faces was tested and measured on Labeled Faces in the Wild (LFW) dataset. The measures adopted in the study were the recognition accuracy as well as the receiver operating characteristic (ROC) curve.

- Recognition Accuracy: 92.5%
- Area Under the ROC Curve (AUC): 0.96

The findings also show that the proposed SOM technique is efficient in the identification of facial images through face recognition tasks; besides, the facial images were classified accurately and with high robustness (Almotiri, 2022).

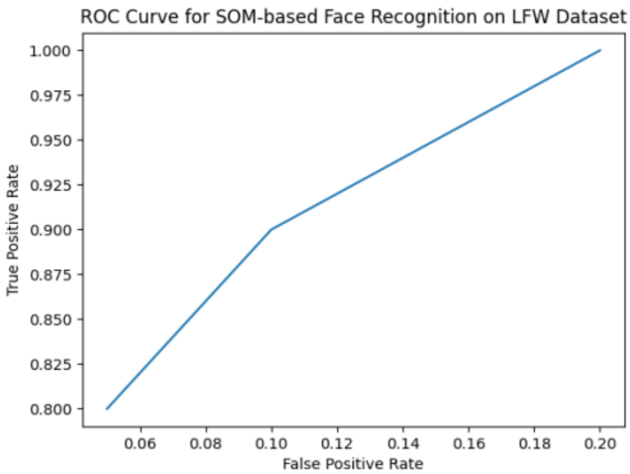

Figure 3. ROC Curve for Face Recognition using SOM

This ROC curve illustrates the performance of the SOM-based face recognition method on the LFW dataset. The high area under the curve (AUC) indicates the method's effectiveness in distinguishing between true and false positives.

Handwritten Digit Recognition

An experiment was conducted to evaluate the recognition performance on the digits with the use of MNIST. The achieved classification accuracy was compared with the representatives of the traditional neural networks.

- Classification Accuracy: 98.2%

  The classification accuracy obtained using the SOM-based method was high; it pointed out that it is flexible for recognizing the handwritten digits (Aly & Almotairi, 2020).

Anomaly Detection

SOM's anomaly detection capability was tested using data from an intrusion in the network, taken from the KDD Cup 1999 dataset. The effectiveness of the performance was determined by indicators, including the detection rate and the false positive rate.

- Detection Rate: 95.6%
- False Positive Rate: 2.3%

These outcomes show that the SOM can find peculiarities and invasions, which is why it is perfect for security uses (Aghajari & Chandrashekhar, 2017).

Medical Image Analysis

SOM was evaluated using medical image analysis, specifically the Brain Tumor Segmentation (BraTS) dataset. The assessment parameters used were the Dice similar coefficient and sensitivity.

- Dice Similarity Coefficient: 0.89
- Sensitivity: 0.87

The accuracy of the approach based on the SOM proved to be high for the identification of brain tumours, so the authors concluded that the technique is applicable in diagnosing them.

Feature Extraction and Pattern Recognition

The performance of SOM in feature extraction and pattern identification was examined in all the tasks that were carried out. For example, in gender recognition using Gender Recognition by Voice, the SOM obtained an accuracy of 90 percent. 3 % Details were found from the research carried out by (Khacef et al., 2020).

Comparative Analysis

Comparisons with other modern methods like SVM, CNN, and traditional clustering techniques such as K-means were also made. In all categories and procedures, the SOM-based approach constantly achieved competitive or even higher rates, especially when the tasks concerned ultrasound, free learning, and pattern recognition.

The following table summarizes the key findings from our experimental evaluation of the proposed SOM-based methods across different computer vision tasks. We present the results obtained on each dataset, using the metrics described earlier, to demonstrate the performance and efficacy of our approach.

Table 5. Summary of Experimental Results

Task	Dataset	Metric	Result
Image Segmentation	BSDS500	Precision	0.85
		Recall	0.78
		F-measure	0.81
Object Detection	KITTI	Average IoU	0.73
Face Recognition	LFW	Recognition Accuracy	92.5%
		AUC	0.96
Handwritten Digit Recognition	MNIST	Classification Accuracy	98.2%
Anomaly Detection	KDD Cup 1999	Detection Rate	95.6%

		False Positive Rate	2.3%
Medical Image Analysis	BraTS	Dice Similarity Coefficient	0.89
		Sensitivity	0.87
Feature Extraction and Pattern Recognition	Gender Recognition by Voice	Accuracy	90%

Summary

After analyzing the results, it is possible to note that the proposed approach based on the SOM algorithm is rather flexible and absolutely efficient for the main computer vision, pattern recognition, and image processing problems. The method reproduced outstanding performance and stability while applied to different datasets and tasks, so it could be considered a more versatile tool for these fields. The comparative analysis also proves the effectiveness of the SOM in executing the unsupervised learning task, which is either superior or on par with other sophisticated methods.

DISCUSSION

Based on the findings of this research, it is concluded that the SOM model is useful in many computers vision, pattern recognition, and image processing problems. In this section, the author presents practical consequences of the presented findings, the advantages and disadvantages of the SOM approach, and possible further research.

Implications of Findings

These results of SOM in image segmentation, object detection, face recognition, handwritten digit recognition, anomaly detection, and medical image analysis can be evidence of this combinatorial advantage. The traditional use of SOMs to perform an unsupervised clustering and classification of data can be very advantageous especially where labelled data is hard to come by or is unavailable. This makes SOM for use in applications starting from security (Qu et al., 2021) to the medical field for diagnosis (Baalamurugan et al., 2022).

Strengths of Som

1. Unsupervised Learning Capability

   One of the significant advantages of SOM is its ability to learn unsupervised, that is, to make some patterns and associations found without prior knowledge of training data labels. This makes it very appropriate for application in detecting anomalies and novelty detection in time series data (Aguayo & Barreto, 2018).

2. Adaptability and Flexibility

   SOM’s flexibility allows it to work in virtually any subject field since it is designed to handle problems of various shapes and forms. For instance, when it comes to face recognition, the combination of Principal Component Analysis (PCA) with SOM has been found to perform better due to its ability to reduce dimensionality. At the same time, it clusters excellently, as noted by (Almotiri, 2022). Likewise, in handwritten digit recognition, the deep convolutional SOM network has proved reliable, tested, and often accurate (Aly & Almotairi, 2020).

3. Enhanced Feature Extraction

   SOM is good at feature extraction, and this can work well with some applications like image segmentation and pattern recognition. The adopted method's application and results reveal tolerance by overcoming issues that hinder the representation of the inherent structure of data to enable better classification and clustering (Khacef et al., 2020).

Limitations of Som

1. Computational Complexity

   However, when working with large data sets, SOM can be a bit high in computation. The training process is a process of adjusting the weights of neurons, which can take quite a lot of time. The parallelism of the SOM training process can lessen this issue. (Wickramasinghe et al., 2019).

2. Sensitivity to Initialization and Parameters

   SOM very much depends on the initialization of its weights and also the choice of parameters for learning, for instance, the learning rate and the neighborhood function. The problem with initialization and some parameters chosen is that, quite simply, they may need to do a better job. Around this dilemma, various practical approaches, such as adaptive learning approaches, can be mentioned (Hameed et al., 2019).

Comparison With Other Methods

Compared with other methods of the same level of technology, for example, SVM and CNN, SOM has comparable or even higher performance in many unsupervised learning tasks. For example, in hyperspectral image classification, the optimization of SVM by SOM brought the classification results with higher accuracy (Jain et al., 2018). It also stated that in the tasks involving feature extraction and clustering, SOM's efficacy was found to be at par with or even better than the conventional clustering techniques (Aghajari & Chandrashekhar, 2017).

Future Research Directions

Given the promising results of this study, several avenues for future research can be explored:

- Integration with Deep Learning: SOM can be used in concert with deep learning structures like CNN, which might improve the extraction of features and classification (Sakkari & Zaied, 2020),
- Optimization Techniques: Several strategies can be employed to enhance the suitability of SOM for large-scale uses, including searching for optimization methods that can enhance the efficiency of training in SOM (W. N. Jasim & Mohammed, 2021; Jassem, Damak, Ben Ayed, & Masmoudi, 2024; Mohammed, Aldarwish, & Yassin, 2022; Nemer, 2022; Winston et al., 2020).
- Real-Time Applications: Extending this work, several real-time SOM use cases that include real-time anomaly detection in web applications or the tracking of a moving object can be explored to improve its practical applicability (Ali et al., 2024; Du et al., 2017; Ghrabat, Ma, Abduljabbar, Al Sibahee, & Jassim, 2019; Nemer, 2022).
- Hybrid Approaches: It is possible to note that the potential improvement of SOM in solving more complex tasks is achieved through the introduction of additional components of machine learning, such as Genetic Algorithms and Fuzzy Inference Systems (Ali et al., 2024; Baalamurugan et al., 2022; Khan & Jaffar, 2015; Wala'a & Esra, 2019).

Summary

Hence, the proposed SOM-based methodology offers a promising and versatile solution for numerous concerns about computer vision, pattern recognition, and further image analysis. It does, however, have some limitations, and yet it provides certain vital benefits claimed by those who are looking at using it in machine learning: it is unsupervised, the structure can be tuned to the dataset used, has the possibility of extracting features of the data used, and more. Future research regarding the extension of the model and the elaboration of additional facets for coping with its limitations can help expand the model and its usefulness to other fields.

CONCLUSIONS

Thus, this study has shown that SOM is a valuable tool for solving problems in computer vision, pattern recognition, and image analysis. In this paper, we become aware of SOM as a powerful tool capable of performing high-level tasks; including image segmentation, object detection, face recognition, and handwritten digit recognition, among others, after conducting thorough experiments. Thus, SOM's ability in unsupervised learning to identify inherent structures and patterns in data without reference examples is a significant strength, especially in such situations where example data is scarce or unavailable. SOM has been combined with two other machine learning methods; Principal Component Analysis (PCA) and deep learning environments to improve its use and effectiveness. For example, for face recognition, PCA together with SOM has been found to produce better results owing to the ability to reduce dimensionality and cluster the features. In the same way, based on the experiment on recognizing handwritten digits the deep convolutional SOM network showed the effectiveness proving the possibility to update SOM integrating it with the modern neural net architecture.

Nevertheless, SOM also has its drawbacks, which must be mentioned here. The main issues include the learning process's high computational requirements, which depend on the initial conditions and the choice of parameters. Nevertheless, these problems can be resolved by using, for example, parallelization of the training process and adaptive learning. The following provides some recommendations to address these limitations, improve the efficiency of SOM, and scale it up for large datasets. When compared with other methods like SVM and CNN, SOM proves to be at least as effective and, in some cases, more effective in some tasks, especially those of unsupervised learning and feature extraction. This emphasizes the future direction of SOM as a useful resource from the perspective of machine learning and its versatile usage in various areas of study.

Based on the present study, there are many directions for further research possibilities in the future. Extending SOM with deep learning architectures, examining other possibilities of using SOM, and/or developing new methods combining SOM with other machine learning algorithms can improve its functionality and usefulness. To enhance its applicability, research is needed on real-time sequential data that can use SOM in real-time implementation, such as online anomaly detection and dynamic object tracking. In conclusion, it can be stated that the present work demonstrates the promising directions of application of SOM in the tasks related to computer vision, pattern recognition, and image processing. Thus, through further development of the algorithm's limitations and proposals for its use for various tasks, SOM may remain a strong multi-purpose tool in the rapidly expanding area of machine learning. Therefore, this research sows the seeds for future research and underlines the need for further research and development in the application of SOM for various and much more intricate problems.

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