Macaw International Journal of Advanced Research in Computer Science and Engineering (MIJARCSE)
ISSN: 2455-4545. / Volume 10, Issue 1, June 2024
https://doi.org/10.70162/mijarcse//2024/v10/i1/v10i106

MACAW PUBLICATIONS
Scientific Research Journals

Review Paper

A Review on Feature Extraction Techniques using Machine Learning

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Received: 10/02/2024, Revised: 15/05/2024, Accepted: 08/06/2024 Published: 30/06/2024

Abstract: Feature extraction plays an essential role in enhancing the performance of machine learning models by identifying and selecting appropriate information from raw data. It offers a comprehensive overview of several feature extraction techniques employed across various domains, including image processing, natural language processing, and sensor data analysis. Methods such as principal component analysis (PCA), k-means clustering, Generative Adversarial Network (GAN), Conditional Generative Adversarial Network (CGAN), Auto encoder, Bag of Words (Bow), Gray-Level-Co-Occurrence Matrix (GLCM) and Linear Discriminant Analysis (LDA) are discovered in detail, highlighting their strengths and limitations. It deliberates the reputation of feature selection standards, dimensionality reduction, and the impact of feature extraction on model interpretability and simplification. Through a comparative analysis of popular feature extraction methods, this work intentions to provide researchers and practitioners with understands into selecting appropriate techniques to optimize model performance in different applications.

Key words: Feature extraction, supervised learning, unsupervised learning, Feature challenges

1 Introduction

Feature extraction is a process in machine learning and data analysis that includes identifying and removing interrelated features from raw data. These features are later used to create an additional informative dataset, which can be further used for various tasks such as:

- Classification
- Prediction
- Clustering

It purposes to reduce data difficulty while remembering as much associated information as possible. This supports to advance the performance and efficiency of machine learning algorithms and simplify the examination process. It may contain the creation of new features and data operations to separate and simplify the use of meaningful features from inappropriate ones. By using feature extraction, it is probable to translate raw data into the required form which we can use for machine learning modeling. It can improve the training speed, The approach advancements the model accuracy, it can reduce the risk of over fitting. The study can be used for better visualization. Machine learning consist of massive datasets that demand important resources to process. It is the active method used to reduce the number of resources required without losing dynamic information. It makes Machine learning more operative. It progresses efficiency and accuracy. Image processing may be performed by eliminating features for identification, classification, diagnosis, clustering, recognition and detection. Feature extraction methods are used to acquire much information as possible of image [1]. Feature extraction plays an energetic role in many real-world applications. It is dangerous for processes such as image and speech recognition, predictive modeling, and Natural Language Processing (NLP).

In these situations, the raw data may contain many unrelated or redundant features. This makes it difficult for algorithms to accurately develop the data. By performing feature extraction, the relevant features are disconnected from the irrelevant ones. With fewer features to process, the dataset becomes simpler and the accuracy and efficiency of the analysis expands. Face detection and facial feature extraction with machine learning includes using algorithms and models to identify faces in images or videos and extract key facial elements like eyes, nose, and mouth. This involves training models on datasets with interpreted facial features, often using convolutional neural networks (CNNs). Once faces are detected, further algorithms can identify specific features, allowing applications like face recognition and emotion detection. This technology is essential in security, human-computer interaction, and entertainment domains [2].

Feature extraction provides a complete overview of the methods in machine learning, covering traditional techniques like PCA, LDA, and GLCM, as well as transform-based methods such as Fourier and Wavelet transforms. It confers statistical approaches like mean, variance, and deep learning methods including CNNs, and autoencoders. The assessment evaluates these methods on criteria like computational efficiency, robustness to noise, and real-world performance, highlighting their strengths, limitations, and potential for hybridization [3].

MACHINE LEARNING ALGORITHMS USING FEATURE EXTRACTION TECHNIQUES

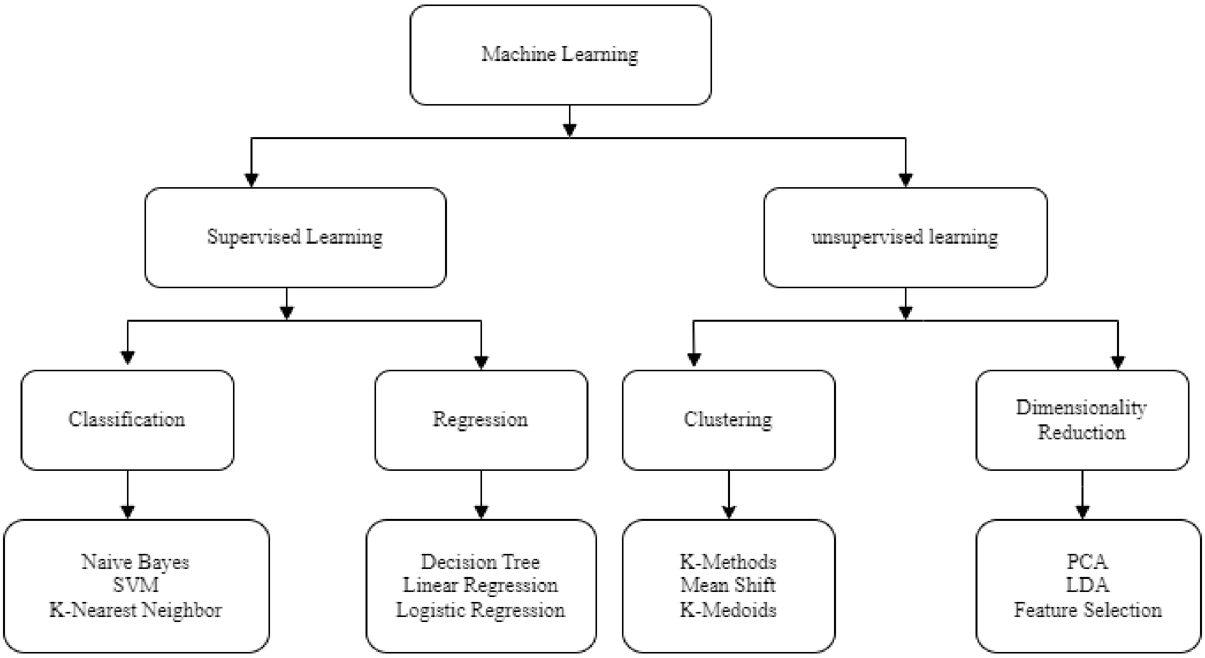

Fig 1: Flow chart of Machine Learning Algorithms

Supervised Learning:

Supervised means to direct the certain activity and make sure it is done correctly. In this type of learning the machine absorbs in the supervision and by feeding them branded data and clearly telling them that this is the input and this is how the output looks. Example- a relation of student and teacher.

A. Classification

Classification in machine learning is a supervised learning mission where the goal is to classify input data into predefined classes or categories. The input data, also known as instances or samples, are signified by features or attributes. The algorithm acquires from a labeled dataset, where each instance is connected with a class label. Naive Bayes, Support Vector Machines (SVM), and K-Nearest Neighbors (K-NN) are all prevalent algorithms used in classification tasks.

- **Naive Bayes:** It is based on Bayes theorem and accepts that features are independent of each other. Despite its simplicity, Naive Bayes can perform well in many cases, especially with a huge number of features.

- **Support Vector Machines (SVM):** SVM aims to find the hyperplane that can separates diverse classes in the feature space. It is effective in high-dimensional spaces and can handle non-linear decision limitations through the use of kernel functions.

- **K-Nearest Neighbors (K-NN):** K-NN classifies data points based on the popular class of their k nearest neighbors. It is simple and easy to understand but can be computationally expensive, especially with bulky datasets.

B. Regression

Regression in feature extraction discusses to the process of using regression techniques to extract relevant features from data. Naturally, regression is used to model the relationship between input features and target variables. In feature extraction, regression can be active to identify which features are most important or to transform the innovative features into a new set of features that are more informative for the task at hand. It includes the techniques such as Decision Tree, linear regression, and logistic regression are all fundamental techniques in machine learning, each serving different purposes:

- **Decision Tree:** Decision trees are useful and easy-to-understand representations used for both classification and regression tasks. It works recursively partitioning the input space into sections, with each section representing a decision. Decision trees are prevalent due to their interpretability and ability to handle unconditional and numerical data without requiring much preprocessing.

- **Linear Regression:** Linear regression is a simple, powerful and statistical method used for predicting a continuous target variable based on one or more input features. It accepts a linear relationship between the input features and the target variable, with the goal of discovering the best-fitting line that minimizes the difference between the actual and predicted values. It is widely used due to its interpretability, computational efficiency, and ease of execution.

- **Logistic Regression:** Logistic regression is a statistical method used for binary classification tasks, where the target variable has two probable outcomes (e.g., yes/no, 0/1). It represents the probability that a given input belongs to a particular class using the logistic function, which confirms that the predicted probabilities are between 0 and 1. Logistic regression is usually used in various fields, including medicine, finance, and social sciences, due to its simplicity, interpretability, and efficiency.

Unsupervised Learning:

Unsupervised means to act without anyone's regulation or any bodies direction. Here the data is not labelled and the machine has to figure out the dataset given and it has to find unseen patterns in order to make estimations about the output. Example- adults like you and me.

C. Clustering:

Clustering is an unsupervised learning technique used to collect a set of objects based on their similarities. The goal is to find natural groupings or clusters within the data without prior knowledge of the groups.

- **K-means:** K-means is one of the most prevalent clustering algorithms. It divides the data into K clusters by iteratively assigning each data point to the nearest cluster centroid and then updating the centroids based on the mean of the points allocated to each cluster. It goals to minimize the within-cluster variance, typically using the Euclidean distance metric.

- **Mean Shift:** Mean Shift is a density-based clustering algorithm that doesn't want specifying the number of clusters in advance. It works by iteratively shifting data points towards the approach of the underlying data density, where the density is estimated based on a kernel function. Data points touch to local density maxima, forming clusters around them. Mean Shift is robust to irregularly shaped clusters and outliers but can be computationally expensive, particularly for large datasets.

- **K-Medoids:** K-Medoids, also recognized as Partitioning Around Medoids (PAM), is parallel to K-means but uses real data points as cluster cores instead of centroids. It aims to minimize the sum of variations between each data point and its nearest medoid. However, it can be computationally expensive as it needs calculating binomial dissimilarities between data points.

D. Dimensionality Reduction:

Dimensionality reduction in machine learning refers to the process of dropping the number of input variables or features in a dataset while recalling the most related information. The primary objective is to simplify the dataset by removing redundant or irrelevant features, thereby decreasing computational complexity, enhancing model performance, and gaining perceptions into the underlying data structure.

- **PCA (Principal Component Analysis):** PCA is a technique used to decrease the dimensionality of the dataset by transforming the innovative features into a new set of immaterial features called principal components. These principal components are well-organized by the amount of variance they capture in the data.
- **LDA (Linear Discriminant Analysis):** LDA is a supervised technique used to discover the feature subspace that maximizes class separability. It aims to find the linear discriminants that maximize the separation between different classes while minimizing the within-class scatter.
- **Feature Selection:** Feature selection involves selecting a subset of the most related features from the original feature set. This subset of features can be selected based on various principles such as statistical tests, feature importance scores, or domain knowledge. Feature selection helps to improve model performance, reduce overfitting, and speed up training by eliminating irrelevant or redundant features.

2. Methods

There are several techniques used for feature extraction, each technique can modify towards explicit types of information and responsibilities. These are some of the real-world practices of feature extraction.

2.1 GAN

A generative adversarial network (GAN) is a deep learning planning. It trains two neural networks to participate against each other to produce more dependable new data from a given training dataset. For example, you can produce new images from an existing image database or innovative music from a database of songs.

2.2 Conditional GANS(CGANS)

In additional GANS laterally with the images as input, additional information is provided as input to the originator and discriminator so that the produced output would be in agreement with the additional information.

2.3 Auto encoder

Auto encoder can recognize significant data features. The auto encoder concept higens on learning from the coding of the original data sets to initiate new, more effective features. In machine learning, autoencoders are neural networks capable to learn efficient representations of data. As for feature extraction, autoencoders encode input data into a lower-dimensional space and then decode it back to its advanced form. The encoded representation supports as a compressed version of the input, effectively removing convenient features. Autoencoders are often used for dimensionality reduction and feature learning tasks in various domains such as image, text, and audio processing.

2.4 Bag of Words (Bow)

Bow is an effective technique in nature language processing where the word used in a text can be extracted and classified by their convention frequency. Bow is one of the approaches that is used for feature selection and classification. This method is hot and has a great ability for selecting and classifying the features by creating bags for each occurrence type.

2.5 GLCM

Gray-Level-Co-Occurrence Matrix is a quality analysis method in image processing. This method represents the association between two neighboring pixels that have gray concentration, distance and angle.

All these techniques are most frequently used in feature extraction using machine learning. Each and every technique have specific functionality and interpretability. These methods are deeply explained and discussed in literature survey.

3. Literature Survey

In this paper, the author explores how Principal Component Analysis (PCA) [4] can improve heart disease classification. The study addresses the problem and emphasizes the importance of feature extraction for accurate classification. The approach reviews current methods in heart disease classification, focusing on PCA's role in dimensionality reduction. The methodology covers the dataset, preprocessing steps, application of PCA, and classification algorithms used. Results indicate the efficiency of PCA in enhancing classification accuracy and computational performance. The discussion highlights the strengths and limitations of the approach, while the conclusion summarizes key findings and suggests future research directions. Overall, the paper demonstrates the potential of PCA in improving heart disease classification, which could ultimately enhance diagnostic accuracy and patient care.

Another study involves extracting key features from facial images to represent them in a lower-dimensional space using PCA [5]. PCA identifies the most significant patterns by reducing the dimensionality of data while preserving essential information. In face recognition, PCA analyzes facial images to capture common features such as the eyes, nose, and mouth. These features are then used to create compressed representations of faces, which are compared during recognition to determine identity. PCA-based face recognition is efficient and widely used due to its ability to reduce computational complexity while maintaining high accuracy.

A novel method for leukemia diagnosis incorporates K-Means clustering and machine learning[6]. The study utilizes unsupervised K-Means clustering to identify patterns in leukemia data, followed by machine learning algorithms for classification. This combination achieves accurate leukemia detection, demonstrating the potential of data-driven methods in medical diagnostics. The paper presents a promising approach with significant implications for improving leukemia diagnosis and treatment planning.

A comprehensive review of Generative Adversarial Networks (GANs) [7] provides an in-depth analysis of their theoretical framework, focusing on the interaction between generator and discriminator networks. The study reviews evaluation metrics, such as Frechet Inception Distance and Precision-Recall scores, and discusses recent advancements in GAN research, including growth techniques and attention mechanisms. GANs are shown to have wide-ranging applications in areas like image generation and data augmentation, making this review a valuable resource for understanding and applying GANs effectively.

Another study introduces an advanced framework for generating synthetic rolling bearing fault samples tailored to new operating conditions. This method employs a modified Conditional Generative Adversarial Network (CGAN) [8]to create fault samples based on existing data, incorporating features representing various operating conditions. The approach generates fault samples that closely mirror real-world scenarios, enhancing the diversity and accuracy of fault representation. The use of CGAN improves fault detection and prognostics, offering a robust solution for advancing fault analysis systems.

A comprehensive overview of autoencoders[9] explores their theoretical foundations, architectures, training techniques, and practical applications in domains such as image processing and natural language processing. This survey serves as an essential guide for researchers and practitioners seeking insights into the principles and applications of autoencoders.

An innovative technique for image compression employs vector-quantized auto-encoders (VAEs) [10] to compress images efficiently while retaining key visual features. By discretizing the hidden space using vector quantization and focusing on semantically meaningful feature extraction, this approach achieves high compression ratios without significant loss of image quality. This method holds significant potential for applications requiring efficient image storage and transmission, such as multimedia, medical imaging, and remote sensing.

A thorough investigation of the Bag of Words (BoW) [11]model addresses its importance in natural language processing tasks like document classification, sentiment analysis, and information retrieval. The study discusses implementation techniques such as TF-IDF weighting and n-gram modeling and explores real-world applications across various domains. Challenges such as vocabulary size limitations, semantic understanding, and computational complexity are also examined. This paper serves as a valuable resource for understanding the theoretical foundations and practical applications of the BoW model in NLP tasks.

An advanced method for categorizing medical X-ray images uses Gray-Level Co-occurrence Matrix (GLCM)[12] for feature extraction combined with machine learning algorithms. This approach effectively identifies relevant patterns within X-ray images, demonstrating potential in supporting healthcare professionals with accurate diagnosis and treatment planning. The paper presents a promising solution for improving medical imaging diagnostics and healthcare delivery

A novel approach to breast cancer classification integrates Linear Discriminant Analysis (LDA) with Support Vector Machine (SVM) techniques[13]. LDA is used to extract features from breast cancer data, optimizing the separation between benign and malignant cases while reducing variation within each class. SVM is then applied to classify cases based on the extracted features, leveraging its ability to handle high-dimensional and nonlinear data. The study demonstrates the effectiveness of this combined approach in accurately classifying breast cancer cases, offering potential improvements in diagnostic accuracy and patient outcomes

A study on IoT network security[14]. explores feature extraction techniques for developing effective intrusion detection systems (IDS) in IoT environments. The paper discusses various feature selection methods, emphasizing the importance of selecting appropriate features to address challenges like the diverse characteristics of IoT devices and communication protocols. This study provides insights into advanced feature extraction methods and evaluates their suitability for enhancing IoT cybersecurity.

4. Future Challenges

While discussing challenges in feature extraction in the situation of data, it is naturally declaring to the process of classifying and selecting related information or characteristics from raw data. Here are some challenges regularly encountered in this area:

Dimensionality reduction: It is the process of dropping the number of features while recollecting the most associated information. It helps to simplify the dataset and can lead to earlier computation, lower storage necessities, and improved model performance by reducing the risk of overfitting. Techniques like principal component analysis (PCA), and autoencoders are commonly used for dimensionality reduction in feature extraction. With the increasing volume and complexity of data, feature spaces can become very high dimensional. This can lead to challenges in computation, visualization, and understanding the relations among features.

Irrelevant or Redundant Features: Not all features in a dataset are interrelated for the task at hand, and some may even be redundant. Identifying and removing these features is important for cultivating model performance and reducing computational overhead.

Feature Engineering: Creating meaningful features regularly wants domain knowledge and creativity. Producing useful features can be challenging, particularly in fields where domain knowledge is constrained or the data is characteristically noisy.

Missing Data: Real-world datasets often cover missing values, which can complicate feature extraction. Dealing with missing data requires careful handling, such as attribution or omission, to avoid biasing the analysis.

Data Quality Issues: Noisy or unpredictable data can challenge the effectiveness of feature extraction methods. Preprocessing segments, such as data cleaning and normalization, are necessary to ensure the quality and reliability of extracted features.

Curse of Dimensionality: As the dimensionality of the feature space increases, the amount of data important to effectively cover the space raises exponentially. This can lead to tasks in modelling and generalization, mainly with limited data accessibility. This can lead to problems such as increased computational complexity, sparsity of information, overfitting, and difficulty in visualization and clarification. Dimensionality reduction methods are often employed to restrained the effects of the curse of dimensionality by reducing the number of features while shielding the most important data.

Overfitting: Eliminating too many features or allowing models to become too problematic lead to overfitting, where the model learns to remember the training data rather than infectious primary patterns. Regularization methods are often employed to moderate this risk.

Interpretability: Compound feature extraction methods, such as deep learning, may result in illustrations that are difficult to understand. Understanding how features contribute to model calculations is important for gaining perceptions and building trust in the model.

Computational Resources: Some feature extraction methods, mostly those concerning on composite algorithms or large datasets, can be computationally comprehensive and needs significant resources in terms of time and hardware.

Scalability: As datasets advance in size, feature extraction methods need to scale efficiently to hold the improved computational demands. Scalability becomes mostly important in big data analytics and real-time applications.

Relevance: It symbolizes to the importance of a feature in describing or distinguishing the information. It is about selecting or creating features that are extreme beneficial for the task at hand, whether it is classification, regression, clustering, or any other machine learning mission. Features that are more associated typically donate more to the performance of the model, while unsuitable features can add noise and decrease performance.

Talking these challenges habitually includes a combination of algorithmic innovation, domain knowledge, and careful examination to find the most effective feature extraction methods for a given task and dataset.

5. Conclusion

The essential role of feature extraction in machine learning is accentuated by its insightful impact on model presentation and interpretability across various domains. It is essential for data analysis, includes techniques like Principal Component Analysis (PCA) for Dimensionality Reduction. By dropping complexity, it improves efficiency, making it a crucial tool in eliminating meaningful outlines from data for better visions and decision-making. Additionally, beyond enhancing model presentation, feature extraction simplifies dimensionality reduction, computational efficiency, and model interpretability. Until now, the interpretability-accuracy balance remains crucial, advice attention of simpler methods to continue transparency in model decision-making. Feature extraction plays a vital role in machine learning by renovating raw data into a more manageable and informative representation. It helps in reducing dimensionality, improving model presentation, and extracting appropriate designs for better decision-making. However, the optimal of feature extraction methods should be carefully considered based on the unambiguous problem domain and data characteristics. By using feature extraction methods in machine learning the challenges can be solved.

Author Contributions: The authors contributed to the research as follows: M. Hari Chandana was responsible for the conceptualization of the research, designing the methodology, and overseeing the entire project. G. Dorasanamma handled data collection, analysis, and the interpretation of results. S. Kiran contributed by implementing the algorithms, providing technical support, and validating the findings. A. Ashok Kumar conducted the literature review, drafted the manuscript, and assisted with editing. All authors played a significant role in bringing the research to completion.

Data availability: Data are available upon request.

Conflict of Interest: There are no conflicts of interest to declare.

Ethics Approval Statement: The study was conducted in accordance with ethical guidelines

Funding: This study received no external funding.

Similarity checked: Yes

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