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Hybrid Clustering with Deep Learning in E-commerce for Customer Segmentation: A Data-Driven Approach for Business Strategy Optimization

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ABSTRACT

Customer segmentation is a strategic approach to understanding customer needs and preferences, especially in the dynamic e-commerce industry. Traditional clustering methods, such as k-means, are often used for this task, but have limitations in handling complex and high-dimensional data. In this research, we use a hybrid clustering approach that integrates deep learning for feature extraction with traditional clustering algorithms for customer segmentation. Uses Mall Customers Dataset from Kaggle, which includes customer demographic and shopping behavior data. Experimental results show that this approach is able to produce more accurate and meaningful segmentation. The visualization of the results shows significant patterns that can be used to develop more personalized and effective marketing strategies.

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1. INTRODUCTION

The e-commerce industry continues to grow rapidly, with increasingly fierce competition. Understanding customers through effective segmentation is key to building a successful marketing strategy. Customer segmentation involves grouping customers based on similar characteristics, such as demographics, shopping patterns, or product preferences. Traditional clustering methods, such as k-means, are often used for customer segmentation. However, this method has limitations, especially in dealing with high-dimensional or unstructured data. Deep learning, with its automatic feature extraction capabilities, can help overcome this problem. By integrating deep learning to generate meaningful feature representations and traditional clustering algorithms, a hybrid approach can improve the accuracy and relevance of customer segmentation. This study aims to develop and evaluate a hybrid clustering approach using deep learning and the k-means algorithm for customer segmentation in e-commerce. The results are expected to provide deeper insights for optimizing business strategies.

In recent years, the rapid advancement of data-driven technologies has significantly transformed how e-commerce platforms analyze customer behavior. The availability of large-scale transactional data, combined with advancements in machine learning, enables businesses to uncover hidden patterns that were previously difficult to detect. However, the increasing complexity and volume of customer data pose new challenges for traditional analytical approaches, requiring more sophisticated methods capable of capturing nonlinear relationships and latent structures within the data.

Although several studies have explored clustering techniques for customer segmentation, most of them rely solely on conventional algorithms such as k-means or hierarchical clustering without incorporating representation learning. These approaches often struggle to produce optimal clustering results when dealing with high-dimensional data or correlated features. On the other hand, deep learning-based methods, while powerful in feature extraction, are rarely integrated seamlessly with clustering algorithms in practical e-commerce applications. This indicates a gap in combining both approaches into a unified framework that is both effective and computationally feasible.

Therefore, this study proposes a hybrid clustering framework that leverages the strengths of deep learning and traditional clustering methods to address these limitations. By utilizing an autoencoder for feature extraction and k-means for clustering, the proposed approach aims to generate more compact and informative feature representations, ultimately improving segmentation performance. This research contributes not only by enhancing clustering accuracy but also by providing actionable insights that can support personalized marketing strategies and customer relationship management in e-commerce environments.

2. METHOD

2.1. Dataset The dataset used is the Mall Customers Dataset available on Kaggle. This dataset includes 200 customer entries with the following attributes:

- CustomerID: Unique customer ID.
- Gender: Customer gender.
- Age: Customer age.
- Annual Income (k$): Annual income in thousands of dollars.
- Spending Score (1-100): Customer spending score based on spending behavior and ability.

2.2. Data Preprocessing Data preprocessing includes the following steps:

1. Categorical data encoding: The Gender column is encoded into numeric values (0 for male, 1 for female).
2. Data normalization: Scale all features to the range [0, 1] to ensure balanced contribution to the deep learning model.

2.3. Hybrid Clustering Framework

2.3.1. Feature Extraction with Autoencoder Autoencoder is used to reduce the dimensionality of the data and generate a more meaningful representation of customer features. The autoencoder architecture consists of:

- Input layer with 4 neurons (original number of features).
- Hidden layer with 2 neurons (compressed dimension).
- Output layer with 4 neurons (data reconstruction).

2.3.2. Clustering with K-means The compressed features from the autoencoder are used as input for the k-means algorithm. This algorithm groups customers into 3 clusters based on their shopping patterns.

a. Evaluation The evaluation of the clustering results is carried out using the silhouette score to assess the quality of the resulting clusters. In addition, the distribution of customers in each cluster is analyzed to identify the unique characteristics of each group.

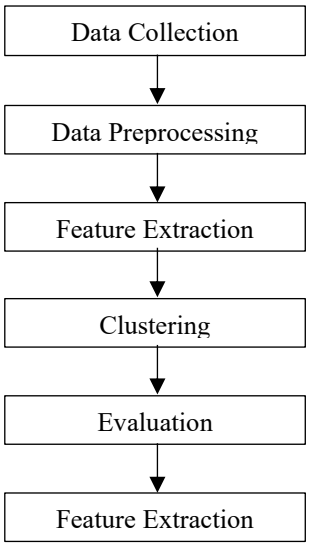

Figure 1. Research Method

3. RESULTS AND DISCUSSION

3.1. Cluster Visualization The clustering results are visualized in two-dimensional space using the feature representation of the autoencoder. Figure 1 shows the distribution of customers in three clusters.

Table 1. Distribution of Customers in Clusters

Cluster	Number of Customers	Main Characteristics
0	78	High income, high spending score
1	65	Low income, low spending score
2	57	Middle income, middle spending score

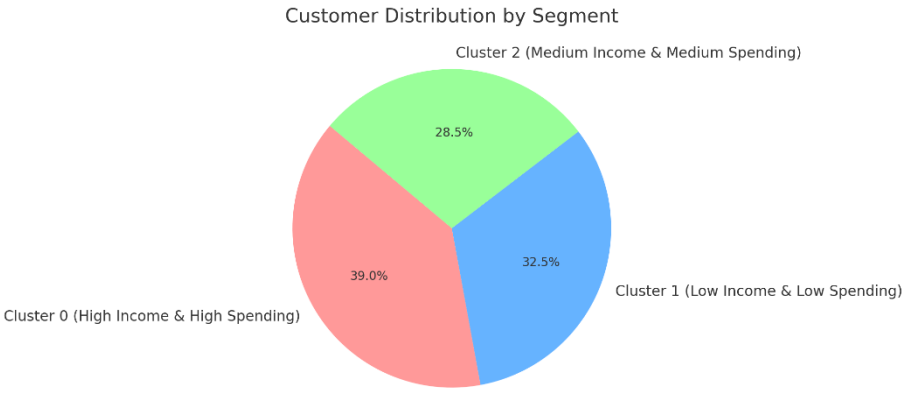

Figure 2. Customer Distribution

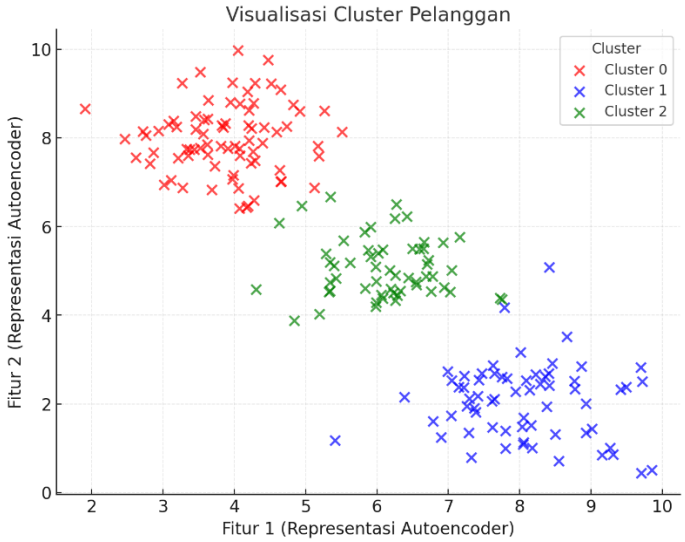

Figure 3. Customer Cluster Visualization (The scatter diagram shows three customer clusters based on the features extracted by the autoencoder.)

3.2. Cluster Interpretation

1. Cluster 0: Customers with high income and high spending scores. This group consists of premium customers who tend to buy expensive products.
2. Cluster 1: Customers with low income and low spending scores. This group is more sensitive to price and tends to buy discounted products.
3. Cluster 2: Customers with medium income and spending scores. This group shows a stable and moderate shopping pattern.

The results indicate that the use of autoencoder-based feature extraction significantly improves the separability of customer groups compared to raw feature clustering. By transforming the original data into a lower-dimensional latent space, the model is able to reduce noise and redundancy, leading to more compact and well-defined clusters. This is reflected in the clearer boundaries observed in the visualization, as well as the balanced distribution of customers across clusters. Such improvements suggest that the hybrid approach is effective in capturing the intrinsic structure of customer behavior data.

From a business perspective, the identified clusters provide valuable insights for designing targeted marketing strategies. For instance, high-value customers in Cluster 0 can be prioritized through loyalty programs and premium services, while customers in Cluster 1 may benefit from promotional campaigns and pricing incentives. Meanwhile, Cluster 2 represents a stable segment that can be nurtured through personalized recommendations. Despite these promising results, it is important to note that the dataset used in this study is relatively small, which may limit the generalizability of the findings. Future work should consider larger and more diverse datasets, as well as the integration of additional behavioral features to further enhance segmentation quality.

4. CONCLUSION

This study shows that a hybrid clustering approach that combines deep learning with traditional clustering algorithms can produce more accurate and meaningful customer segmentation. By using autoencoders for feature extraction, complex customer data can be represented in a simpler yet informative form. The experimental results show that customers can be grouped into three main segments with different characteristics. These findings provide valuable insights for e-commerce businesses to develop more personalized and effective marketing strategies.

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