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A Multi-Criteria Collaborative Filtering Approach Using Deep Learning and Dempster-Shafer Theory for Hotel Recommendations

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Abstract: This research proposes a novel hotel recommendation system that addresses the limitations of single-criterion ratings by utilizing a multi-criteria collaborative filtering approach. The system integrates matrix factorization with a deep neural network to predict individual criteria ratings and employs Dempster-Shafer Theory (DST) to handle uncertainty in those predictions. By aggregating multiple ratings using evidential reasoning, the system provides a robust overall hotel recommendation. Experiments conducted on a real-world TripAdvisor dataset show the proposed method achieves superior accuracy compared to traditional and state-of-the-art models in terms of MAE, RMSE, and Coefficient of Determination.

Keywords: Hotel recommendation system, multi-criteria collaborative filtering, deep learning, matrix factorization, Dempster- Shafer theory, evidential reasoning.

I. INTRODUCTION

In the era of digital transformation, personalized recommendation systems (RS) are integral to various online platforms, including e- commerce, streaming services, and tourism. In hotel selection, travelers consider multiple factors such as price, location, cleanliness, and service. Traditional RS methods that rely on single-criterion ratings often fail to capture the complexity of user preferences. Multi- criteria recommender systems (MCRS) offer a richer representation of user feedback but face challenges in modeling uncertainty and aggregating diverse preferences. This study introduces a deep neural network integrated with matrix factorization to predict ratings across several criteria. Dempster-Shafer Theory is applied to manage the uncertainty inherent in user reviews. The proposed system combines individual ratings through evidential reasoning to generate a final recommendation. This holistic approach improves prediction accuracy and user satisfaction by aligning more closely with actual traveler preferences.

A. Motivation

Traditional hotel recommendation systems using single-criterion ratings do not reflect real-world decision-making complexity. Users evaluate hotels based on multiple attributes, and accounting for the uncertainty in these ratings is critical. This research aims to enhance recommendation accuracy by combining deep learning with DST to handle multiple, uncertain inputs effectively.

II. LITERATURE REVIEW

J. Pérez-Marcos and V. L. Batista: In this paper we propose a methodology based on collaborative filtering to recommend music for Spotify's users from an ordered list of the most played songs over a period of time.

P. Covington, J. Adams, and E. Sargin: The paper is split according to the classic two-stage information retrieval dichotomy: first, we detail a deep candidate generation model and then describe a separate deep ranking model. We also provide practical lessons and insights derived from designing, iterating and maintaining a massive recommendation system with enormous user- facing impact.

W. Jian, J. He, K. Chen, Y. Zhou, and Z. Tang: In this paper, we propose two recommendation models to solve the CCS and ICS problems for new items, which are based on a framework of tightly coupled CF approach and deep

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learning neural network. A specific deep neural network SADE is used to extract the content features of the items. The state of the art CFmodel, timeSVD++, which models and utilizes temporal dynamics of user preferences and item features, is modified to take the content features into prediction of ratings for cold start items

M. Nilashi, A. Ahani, M. D. Esfahani, E. Yadegaridehkordi, S. Samad, O. Ibrahim, N. M. Sharef, and E. Akbari:In this paper, we aim to develop a new soft computing method with the aid of machine learning techniques in order to find the best matching eco-friendly hotels based on the several quality factors in TripAdvisor. We develop the method using dimensionality reduction and prediction machine learning techniques to improve the scalability of prediction from the large number of users' ratings.

S. Zhang, L. Yao, A. Sun, and Y. Tay: This article aims to provide a comprehensive review of recent research efforts on deep learning based recommender systems. More concretely, we provide and devise a taxonomy of deep learning based recommendation models, along with providing a comprehensive summary of the state-of-the-art. Finally, we expand on current trends and provide new perspectives pertaining to this new exciting development of the field.

R. Wang, H. K. Cheng, Y. Jiang, and J. Lou: Collaborative Filtering (CF) algorithms have been widely used to provide personalized recommendations in e-commerce websites and social network applications. Among them, Matrix Factorization (MF) is one of the most popular and efficient techniques. However, most MF-based recommender models only rely on the past transaction information of users, so there is inevitably a data sparsity problem. In this article, we propose a novel recommender model based on matrix factorization and semantic similarity measure.

M. He, S. Zhang, and Q. Meng: This is because the visual appearance of products has a significant impact on consumers' decisions. Extensive studies have been done to integrate the features extracted by convolutional neural networks directly into recommendations. This improves the performance of recommender systems. Style features, an important type of features, are rarely considered. Style features play a vital role in the visual recommendation as a user's decision depends largely on whether the product fits his/her style.

Q. Shambour: Recommender systems have become exceptionally widespread in recent years to deal with the information overload problem by providing personalized recommendations. Multi-criteria recommender systems proved to have more accurate recommendations compared to single-criterion recommender systems as multi-criteria rating reflects the user appreciation of an item in terms of many aspects.

III. PROPOSED SYSTEM

The proposed hotel recommendation system integrates deep learning with Dempster-Shafer Theory to effectively handle multi- criteria ratings and uncertainty in user preferences. It begins with a Deep Neural Network (DNN) that uses matrix factorization via Singular Value Decomposition (SVD) to learn latent features of users and hotels. These embeddings are passed through multiple ReLU-activated layers to predict ratings across several hotel aspects like cleanliness, service, location, and value. Instead of treating these predictions independently, the system models each predicted rating as a piece of evidence using Dempster-Shafer Theory. This allows uncertain or incomplete ratings to be represented as mass functions. The system then applies a discounting mechanism to weigh each criterion based on its importance and combines them using Dempster's rule. The aggregated evidence is finally converted into a single overall rating through a pignistic transformation. This approach not only improves prediction accuracy but also offers a more robust and interpretable recommendation system for hotel selection.

Algorithm

DNN_DST Algorithm
This method integrates:

- **Matrix Factorization (SVD)**: For latent feature extraction of users/items.
- **Multilayer Perceptron (MLP)**: For rating prediction.
- **Dempster-Shafer Theory**: To model uncertainty and combine multi-criteria ratings.

The algorithm predicts individual ratings, models them as evidence, and combines them for a final overall score.

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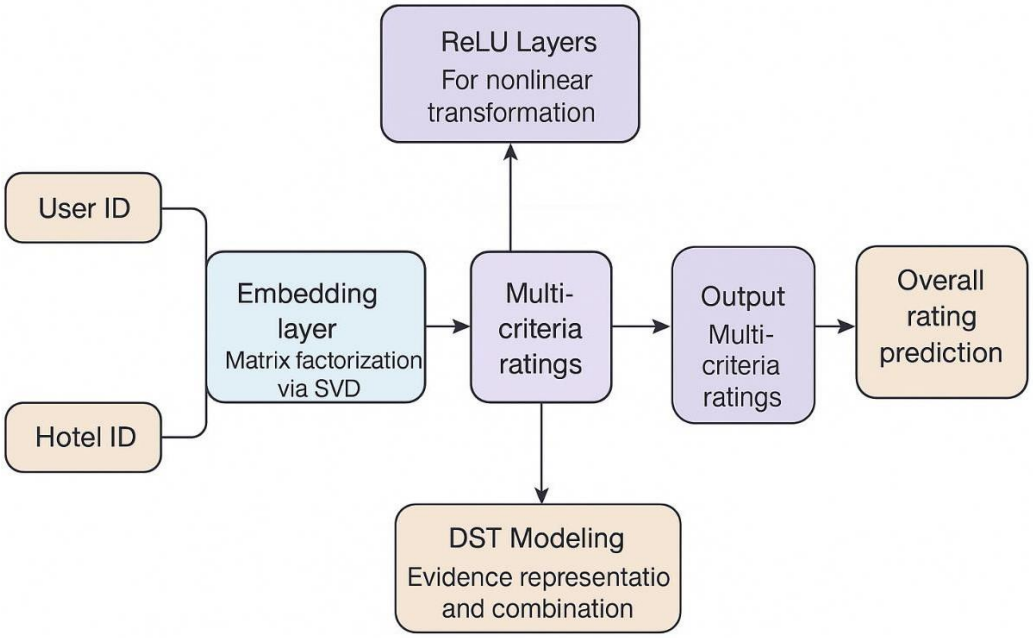
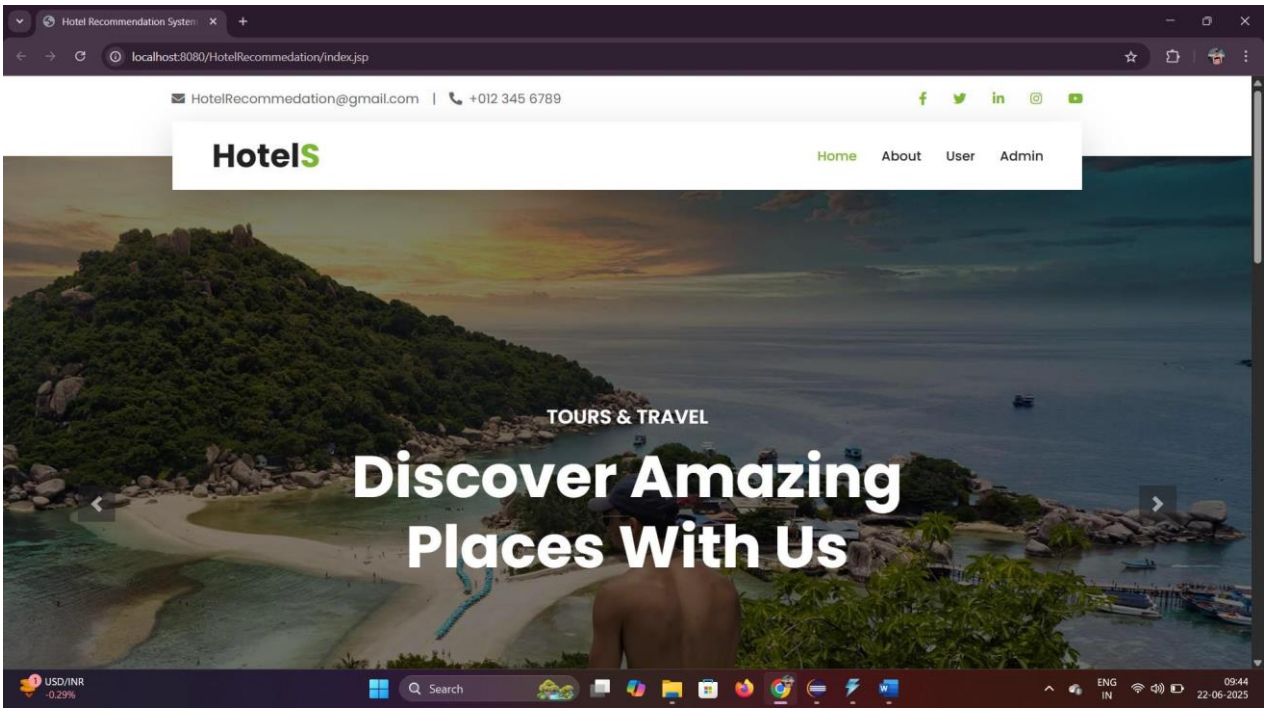


Figure 1. System Architecture

IV. RESULTS AND DISCUSSION



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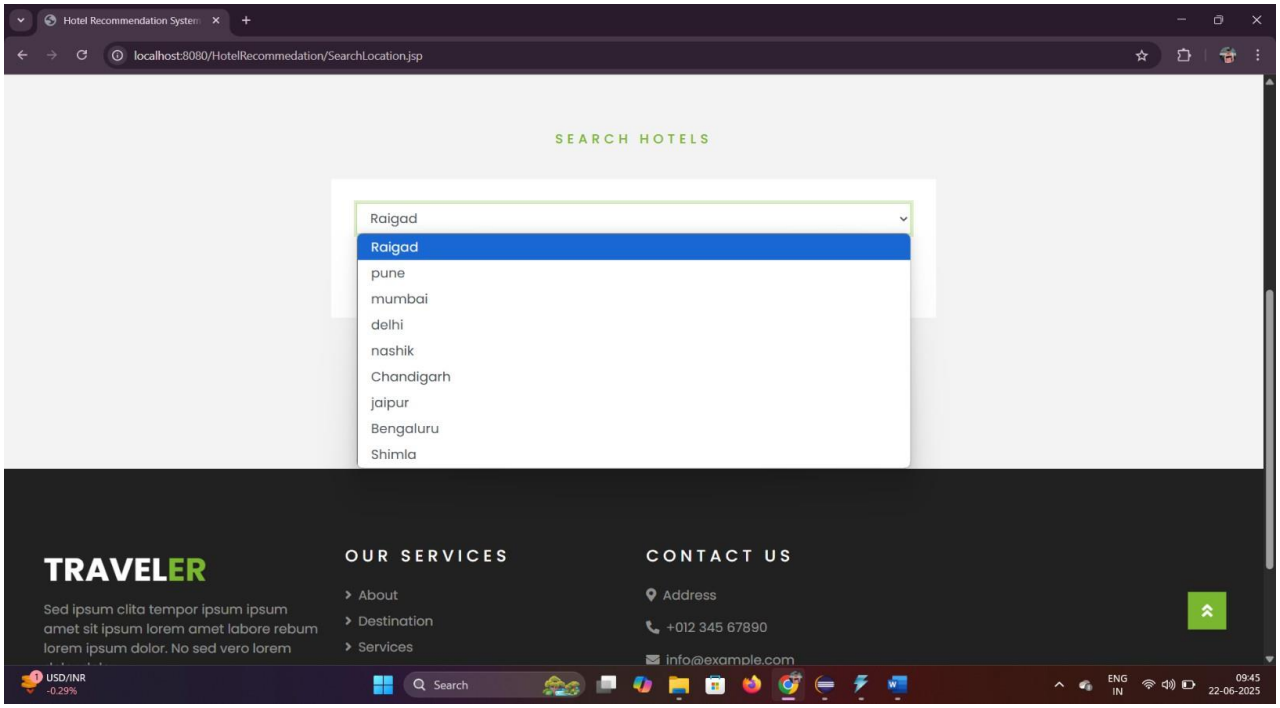

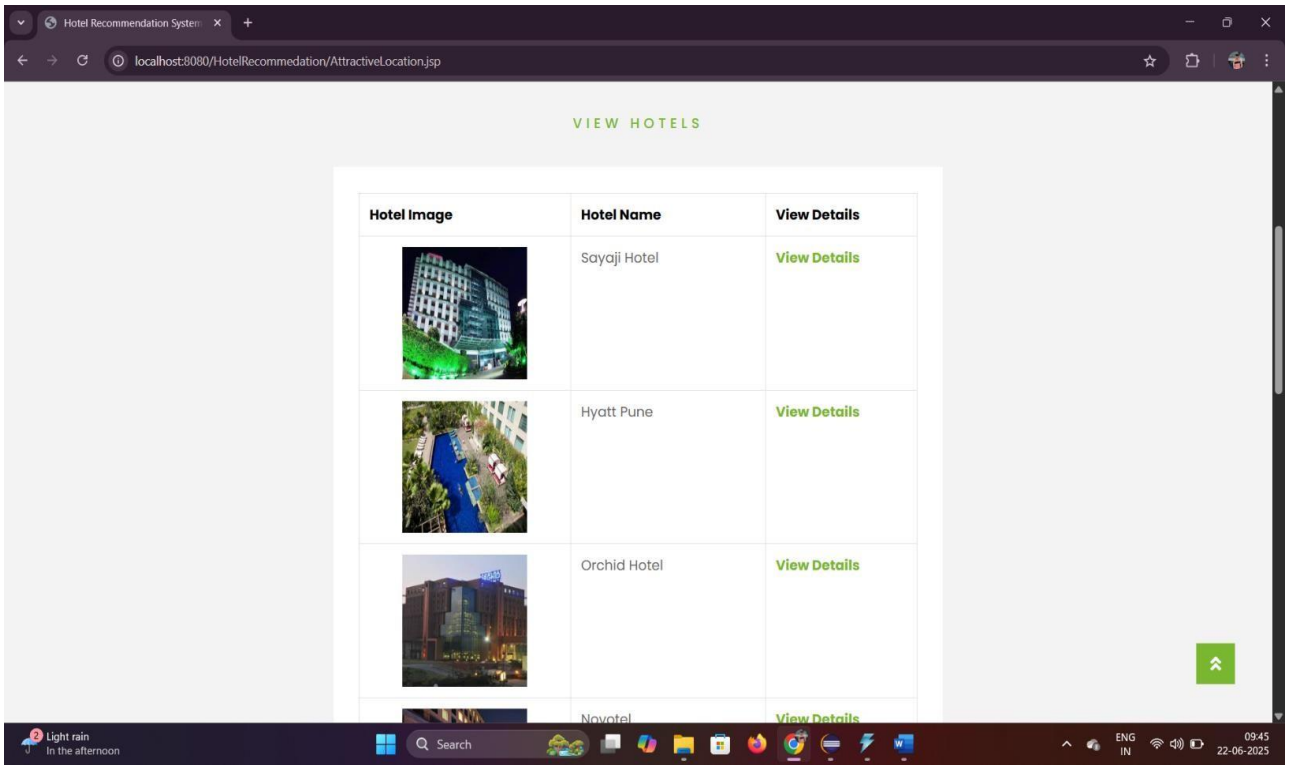

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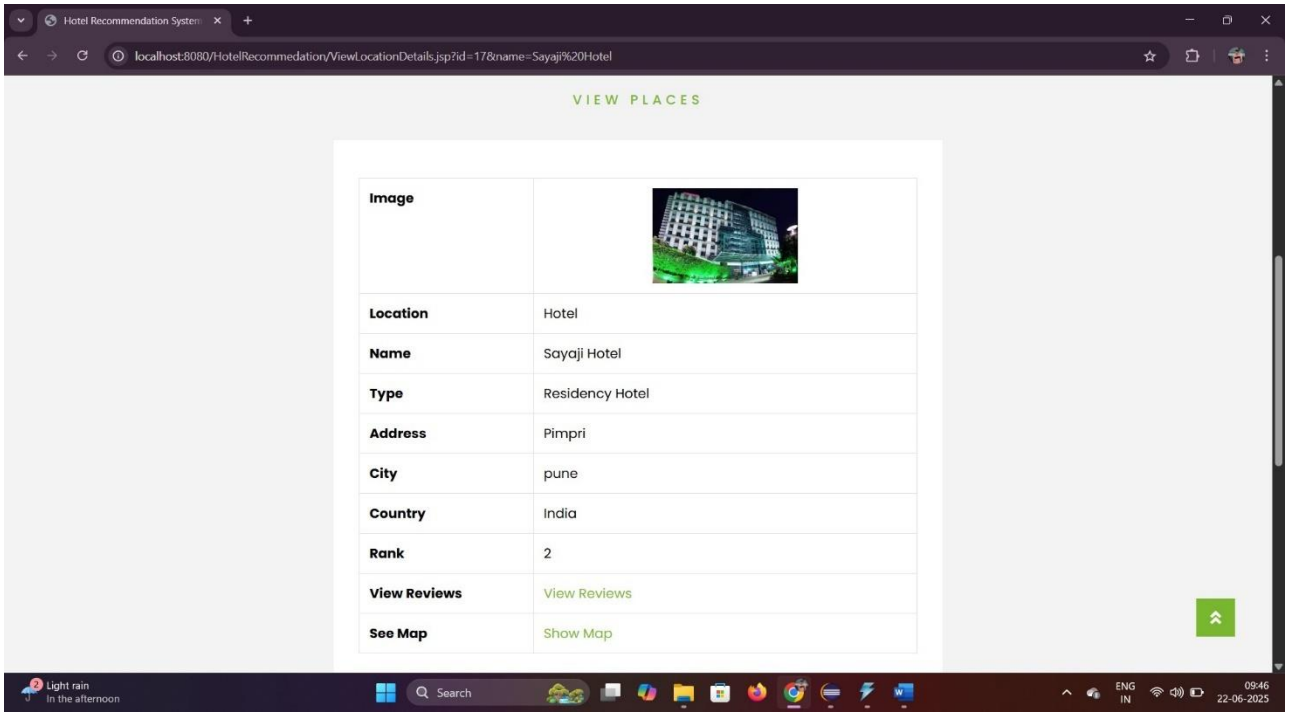

V. CONCLUSION

The DNN_DST model significantly improves hotel recommendation accuracy by integrating deep learning with evidential reasoning. It addresses uncertainties in user ratings and offers a more nuanced approach to multi-criteria recommendation. Compared to conventional and state-of-the-art models, it performs better across standard evaluation metrics while maintaining reasonable efficiency.

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