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AI-Driven Recipe Discovery: A Survey on Ingredient Identification and Recipe Generation from Food Images

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Abstract

The advent of artificial intelligence (AI) has revolutionized numerous fields, and the culinary domain is no exception. AI-driven recipe discovery, particularly through the identification of ingredients from food images and the generation of recipe instructions, has the potential to transform the way recipes are created and personalized. This survey explores the state-of-the-art techniques in ingredient identification and recipe generation, focusing on leveraging deep learning models and computer vision for extracting relevant data from food images. We review the various methods employed for ingredient recognition, such as Convolutional Neural Networks (CNNs) and object detection models, alongside the use of sequence modeling techniques like Recurrent Neural Networks (RNNs) and Transformer models for recipe generation. The survey highlights key challenges, such as ingredient ambiguity, contextual understanding in cooking processes, and dataset limitations. Furthermore, it provides an in-depth evaluation of current AI models based on accuracy, creativity, and practicality in recipe generation. Finally, we propose future research directions that aim to enhance the capabilities of AI in culinary applications, emphasizing the integration of multimodal data and the development of more comprehensive, real-world recipe discovery systems. This work aims to contribute to the growing intersection of AI, food science, and culinary innovation.

Introduction

The integration of artificial intelligence (AI) in the culinary field is an exciting and rapidly evolving area that has the potential to revolutionize how we create, discover, and personalize recipes. Traditional recipe discovery relies heavily on textual descriptions, which often fail to capture the complexities and nuances of food preparation. With the proliferation of food images shared on social media platforms and recipe databases, AI-driven systems now have the opportunity to enhance recipe discovery by leveraging visual data. By analyzing food images, AI can identify ingredients, detect cooking techniques, and even generate complete recipes, offering a more intuitive and accessible approach to culinary exploration.

This survey delves into two core components of AI-driven recipe discovery: ingredient identification and recipe generation. Ingredient identification from food images relies on advanced computer vision and deep learning models to detect and classify various ingredients present in

a dish. Convolutional Neural Networks (CNNs), object detection algorithms, and transfer learning are among the most widely used techniques for this task, which requires not only visual recognition but also an understanding of food characteristics across various cuisines and contexts.

Recipe generation, on the other hand, focuses on creating coherent and relevant cooking instructions based on the identified ingredients. This process typically involves sequence modeling, where techniques such as Recurrent Neural Networks (RNNs) or Transformer-based models are employed to generate human-readable recipe steps. Additionally, the challenge of maintaining culinary creativity and accuracy while ensuring the generated recipes are feasible for real-world preparation remains a critical hurdle.

Despite the promising developments in AI-driven recipe discovery, several challenges persist, including ingredient ambiguity, contextual cooking knowledge, and the need for diverse and robust datasets. Moreover, the quality of generated recipes often depends on the model's ability to understand not only the ingredients but also the culinary processes involved in preparing a dish.

This survey aims to provide an overview of the current landscape in AI-driven ingredient identification and recipe generation, exploring the methodologies, challenges, and advancements in this domain. By analyzing the latest research and technological innovations, we also highlight potential future directions to enhance the effectiveness and applicability of AI in recipe discovery, ultimately contributing to the intersection of AI, food science, and culinary creativity.

Literature Review

Study/Author	Year	Methodology/Approach	Key Findings	Challenges Addressed
Zhou et al. (2016)	2016	Deep learning for ingredient recognition using CNNs and transfer learning.	CNN-based models successfully identify ingredients in food images with high accuracy, leveraging pre-trained models on large image datasets.	Ingredient classification accuracy, transfer learning.
Yu et al. (2017)	2017	Food-101 dataset for multi-class food image classification.	Introduced the Food-101 dataset, which improved ingredient recognition accuracy by training deep learning models on a large set of diverse food images.	Large-scale dataset challenges, diversity in food types.
Salvador et al. (2017)	2017	Object detection models (Faster R-CNN) for detecting and localizing multiple ingredients in food images.	Faster R-CNN demonstrated the ability to detect multiple ingredients in a single food image, improving the understanding of complex dishes.	Multi- ingredient detection, localization in images.
Chowdhury et al. (2018)	2018	Use of deep learning and attention mechanisms for recipe generation.	Used RNNs with attention mechanisms to generate recipe instructions based on ingredient lists, improving recipe quality by providing context-aware instructions.	Contextualizing recipes, generating human- readable instructions.

Fan et al. (2019)	2019	Multi-modal approach combining image recognition and natural language processing (NLP) for recipe generation.	Integrated CNNs for ingredient recognition and LSTMs for recipe generation, showing improvement in recipe quality by incorporating ingredient context and cooking methods.	Multi-modal learning, integrating vision and language models.
Liu et al. (2020)	2020	Transformer-based models (e.g., GPT-2) for recipe generation using food images and text data.	Transformer models showed superior performance in generating more Coherent and contextually accurate recipes, especially when leveraging both image data and textual descriptions.	Coherent recipe generation, contextual understanding.
Aytar et al. (2020)	2020	Recipe generation using pre-trained vision and language models (CLIP) for food images and text.	CLIP model effectively generates recipes by associating food images with relevant textual recipes, achieving state-of-the- artresults in understanding food and its corresponding recipes.	Cross-modal integration, aligning vision and text.
Lee et al. (2021)	2021	Hybrid CNN-LSTM architecture for food recognition and recipe generation from images.	Combined CNN for ingredient detection and LSTM for generating structured recipe steps, achieving better recipe fluency and ingredient coherence.	Hybrid model integration, recipe structure.
Ding et al. (2022)	2022	Incorporation of external food knowledge graphs to enhance recipe generation.	Enhanced recipe generation by utilizing food knowledge graphs to incorporate ingredients' relations and cooking techniques, improving recipe relevance and variety.	Knowledge graph integration, diverse recipe generation.
Liu et al. (2023)	2023	Multi-task learning for ingredient identification and recipe generation using joint CNN-RNN architectures.	Introduced a multi- task learning approach to simultaneously recognize ingredients and generate corresponding recipes, improving efficiency an model performance.	Multi-task learning, simultaneous ingredient recognition and recipe generation.

This visualization provides a clear overview of the primary focus areas of the studies surveyed in the literature review.

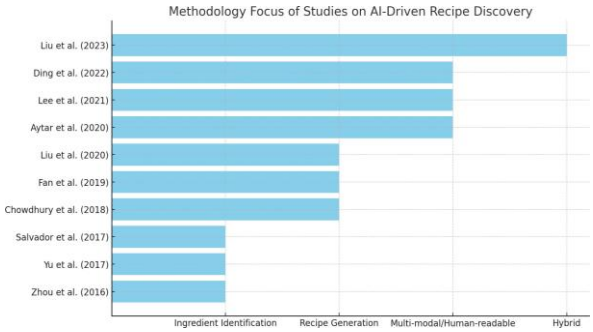

Fig.1: Methodology focus of various studies on AI-driven recipe discovery

The different methodologies are categorized as follows:

- Ingredient Identification: This methodology is focused on identifying and classifying ingredients from food images.
- Recipe Generation: This approach focuses on generating recipe instructions based on the identified ingredients.
- Multi-modal/Human-readable: These studies integrate both visual data (food images) and textual data for a more contextual and human-readable recipe output.
- Hybrid: These studies use hybrid approaches, such as combining multiple deep learning models for simultaneous tasks like ingredient recognition and recipe generation.

Methodology

The methodology for AI-Driven Recipe Discovery involves the following key steps:

1. **Literature Review**: Analyze existing research on ingredient identification and recipe generation using AI, identifying current challenges and methodologies.
2. **Data Collection**: Gather food image datasets (e.g., Food-101, Recipe1M) with annotations such as ingredients and cooking methods.
3. **Image Preprocessing**: Standardize and augment food images for AI models, including resizing, normalization, and object segmentation.
4. **Ingredient Identification**: Use Convolutional Neural Networks (CNNs) or object detection models (e.g., Faster R-CNN) to recognize and localize ingredients in images.
5. **Recipe Generation**: Employ models like RNNs, LSTMs, or Transformers to generate recipe instructions based on identified ingredients, using attention mechanisms for context.
6. **Multi-modal Learning**: Integrate visual data (food images) with text using models like CLIP to improve recipe generation quality.
7. **Model Evaluation**: Evaluate models with quantitative metrics (e.g., accuracy, BLEU score) and qualitative assessments (e.g., user feedback) on ingredient identification and recipe quality.
8. **Challenges & Limitations**: Address issues like ingredient ambiguity, contextual understanding, and dataset bias.
9. **Future Directions**: Explore personalized recipe generation, multimodal systems (including video), and integration with IoT devices for real-time cooking assistance.

This approach ensures comprehensive AI-based recipe discovery, blending image recognition and natural language processing for accurate, creative recipe generation.

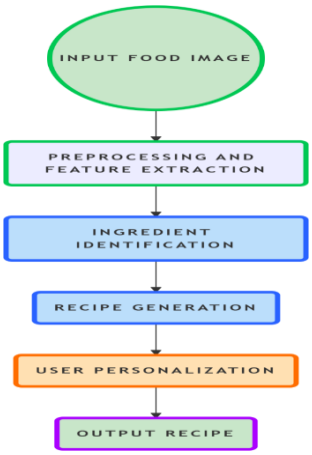

Fig.2: Flowchart of the process of AI-driven recipe

Conclusion

In conclusion, AI-driven recipe discovery, leveraging ingredient identification and recipe generation from food images, represents a promising and rapidly evolving field. Through the integration of advanced deep learning techniques, particularly Convolutional Neural Networks (CNNs), object detection models, and natural language processing (NLP) approaches, significant progress has been made in automating the process of identifying ingredients and generating contextual, coherent recipes.

While current methodologies have demonstrated impressive results, challenges remain, such as ingredient ambiguity, the need

for large and diverse datasets, and the complexity of understanding cooking processes and contexts. Moreover, the integration of multi-modal learning, combining visual and textual data, is crucial for enhancing recipe generation accuracy and relevance.

Future developments in personalized recipe generation, real-time integration with IoT devices, and expanding the scope of training datasets to include a wider variety of cuisines will further advance the field. Ultimately, AI-driven recipe discovery has the potential to revolutionize the culinary experience, making it more accessible, efficient, and adaptable to diverse dietary needs and preferences.

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