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TY B. TECH

ARTIFICIAL INTELLIGENCE

FORMATIVE ASSESSMENT - 2 REPORT

CASE STUDY: **AUTONOMOUS SMART KITCHEN PLANNER**

Submitted By:

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Abstract

The Autonomous Smart Kitchen Planner looks toward solving the problems related to the planning of meals in the context of AI-based Constraint Satisfaction Problem (CSP) techniques. The approach suggests the planning constraints, such as which items are available, what diets are followed or how long it takes to prepare the meal in question, can be met. The paper explains the use of backtracking, forward checking, and constraint propagation in CSP based algorithms and shows the way these strategies improve the performance of the planner. This research also explores the future possibilities of using IoT for proactive management of the kitchen context and presents a current picture and the potential of such systems in smart kitchen environments.

Keywords

Autonomous Cooking Systems, Machine Learning, Modular Robotics, Hazardous Gas Detection, User Preference Modeling, Data Collection for Smart Homes, Distributed Constraint Optimization, Service Robots, Task and Motion Planning, Smart Appliance Scheduling, Real-Time Monitoring, Energy-Efficient Scheduling, Human-Robot Interaction, RESTful Web of Things, Proprioceptive Manipulator, Activity Prediction, Sensor Integration, Constraint-Based Scheduling, Power Optimization, Case-Based Reasoning, Environmental Sensing, Smart Home Automation, Robotic Manipulators, Context-Aware Computing

Introduction

The kitchen is becoming an important space for the adoption of smart technology because consumer demand has been on the rise for personalized and efficient culinary solutions. Because of busy lives and stronger awareness concerning diets, users have been looking for systems that can better streamline meal planning without compromising on individual preferences and nutritional requirements. The Autonomous Smart Kitchen Planner answers that need by automatically planning meals using the CSP algorithm to satisfy multiple, often conflicting, constraints that could occur, such as ingredient availability, dietary preferences, or preparation time.

The innovation at its heart is the CSP algorithm applied to artificial intelligence, a core technique that has widely been applied to solve complex problems which have many constrained satisfactions. Some commonly applied areas include scheduling, logistics, and resource allocation. These are further eased when systems can effectively navigate intricate requirements, just as meal planning would fit particularly well within a smart kitchen environment. For example, in a kitchen automation environment, some restrictions may be ingredient availability, dietary problems such as vegan, gluten-free, low-carb, preparation time, and user-specific requirements. Introducing CSP in the framework design of the system, the kitchen planner both proposes recipes and enforces these in real-time, ensuring that every meal plan is consistent with what the user desires.

The motivation for the Autonomous Smart Kitchen Planner comes from the deficiencies found in the current meal planning and recipe recommendation systems. Although such systems provide a minimum level of functionality, they are frequently insufficient in managing the reality of kitchen constraints, including running out of certain ingredients or adjusting to unexpected changes in schedule. Many of the available solutions forget to include the optimization of ingredient usage. This would lead to avoidable food waste. Also, such systems rarely are adept at offering the needs of individual customers for personalized nutritional results. This autonomous smart kitchen planner fills this gap by including CSP algorithms that allow the system to adapt efficiently within constraints with minimal waste. In doing so, the system can serve the convenience of users while aligning with the environment for sustainability.

This paper mainly aims to prove how the development of Autonomous Smart Kitchen Planner can be achieved through an example and applied on various evolving constraints of real-world kitchen management by CSP.

Objective

Intelligent Menu Planning: Create personalized meal plan algorithms — algorithms that generate meal plans suggestions based on user preferences (dietary preference, time-needed-to-cook, utensil available, etc).

Recipe Recommendation: Build out a large recipe database and organize by cuisine, type, and complexity Building recommendation systems to recommend relevant recipes according to user preferences and available ingredients.

Ingredient Optimization: Break down recipes and determine the best amounts of each ingredient that will reduce waste and increase flavor. Have plans for swapping ingredients and reusing leftovers.

Cooking Process Automation: Smart kitchen appliances: Connect with smart kitchen appliances to automate cooking tasks, such as controlling temperature, timing, and dispensing ingredients.

User Interface Design: Provide user-friendly user interfaces for web-based and mobile platforms so that users may engage with the system. Compose detailed cooking directions and provide useful illustrations.

Provide Efficient Meal Planning: A clever system that can prepare well-balanced meals according to user preferences, dietary requirements, and available ingredients.

Optimize Inventory: Track your ingredients, expiry dates, and suggest recipes based on available items to avoid food wastage.

Intelligent Recipe Selection: AI based algorithms that automatize recipe suggestions on the basis of user preference, dietary restrictions and nutritional guidelines

Provide guidance about the cooking steps: Give guiding instructions while preparing a meal, throughout the processes the instructions adjust according to the pace of the user.

Tailor Recommendations: By tracking user behaviors, eventually suggest new recipes or tweaks suited to individual health goals and personal taste.

IoT Devices Integration: Connect it with that which is available in your smart kitchen to automate some steps such as setting the oven or cooking time etc.

System Architecture

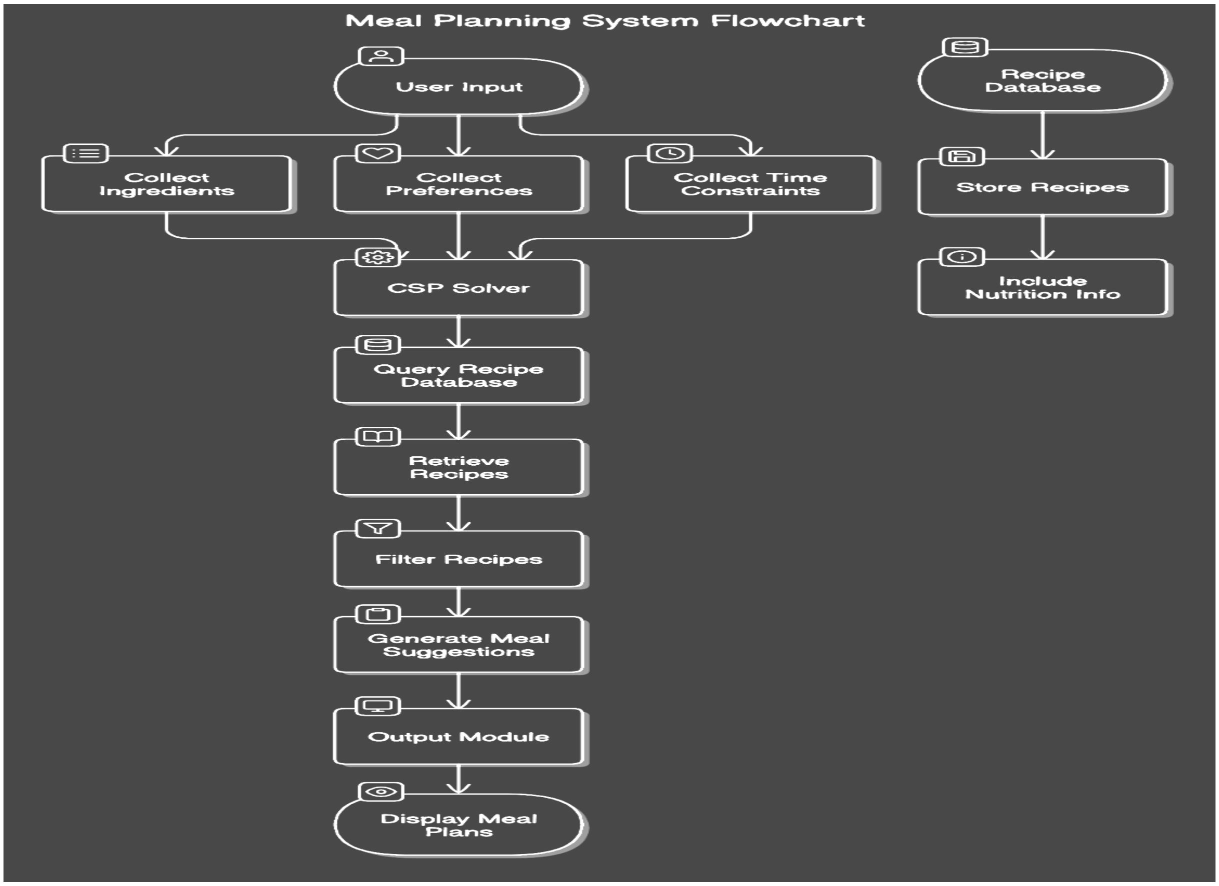
Architecture of the three-level system. It is composed of three functional modules, explicitly defined: User input and constraints Module, CSP Solver, and Recommendation Output Module which are all interdependent in the process for an effective desired meal planning that is within user defined constraints or limitations requirements.

1. User Input and Constraints Module
   - Input Layer: This concept is directed to the user and touches upon his available products, ideas regarding a meal combination, and limitations caused by the type of the meal (e.g. vegan, low-carb). Here also, health-related (e.g. low-sugar for diabetic users) or resource-related (e.g. time availability in case of quick recipes) constraints are defined.
   - Constraint Filtering: The input is filtered to pinpoint hard constraints and soft constraints, soft ones are filters, hard ones must be followed.

2. CSP Solver
   - Verification and Constraint Satisfaction Engineering: The CSP solver has recursion and backtracking as well as forward checking algorithms built into it for searching feasible solutions with regard to the input constraints.
   - Heuristic based Modelling and Optimization techniques: These are incorporated so that response time and efficiency are boosted and even when the system is faced with simultaneous constraints the performance is still satisfactory
   - Decision Tree for Meal Selection: The solver creates a dependent structure by formulating the decision that each branch has a value meal. Further along into the implementation process, techniques for pruning the tree and removing infeasible options that breach hard constraints are implemented.

3. Recommendation Output Module
   - Recipe Recommendation: The module suggests a list of scaling solutions which also meet the set constraints when the problem is resolved. Factors such as preparation time and the efficiency of ingredients used also come into play when ranking these recipes.
   - Interactive Feedback: Users can endorse or reject the recommendations as well as the default meal setting and their changes will be taken into account while planning in the future.
   - Future Expansion: IoT Integration

4. Currently, the integrated system is mainly designed for promoting directly the meal planning through CSP, however it can evolve in future versions which would have IoT integration where real-time information can be availed on the use of ingredients, automated stock control, and availability of kitchen gadgets.



Literature survey

Recent developments in smart kitchen systems represent the convergence of Internet of Things (IoT), artificial intelligence (AI), robotics, and safety technologies. IoT-based systems have become foundational in enabling connected kitchens, with **Chatterjee et al. (2018)** discussing the basic architecture of smart kitchens that link various devices to streamline kitchen operations and enhance convenience through automation and remote access [1]. **Vu and Khanna** build on this by exploring the use of AI in the kitchen, specifically how smart systems can anticipate human needs and change kitchen conditions to help complete cooking tasks efficiently [2]. **Noh et al**. present a modular structure with their YORI autonomous cooking system, using a dual-arm manipulator to ensure safe and precise cooking, thereby demonstrating progress in robot support in the kitchen [3].

One of the major concerns in the design of the smart kitchen is safety, especially for vulnerable populations like the elderly. **Geng et al. (2023)** addressed this with a targeted solution by proposing a kitchen safety protection system for "empty nesters," or older adults living alone, using IoT sensors to monitor environmental factors and alert users to potential hazards, such as gas leaks [4]. For instance, **Kumar et al. (2024)** consider machine learning integration into hazardous gas detecting systems that highlight the importance of real-time monitoring as a prime tool toward health safety conditions in cooking zones [5].

The area of smart home management regarding energy involves scheduling that helps manage the consumption of energy at each kitchen or kitchen section involved. **Makhadmeh et al.** presented detailed survey work on the optimization of smart home power scheduling along with few approaches applied towards kitchen appliances to reduce consumption through optimizing techniques [6]. **Ali et al.** published the paper on time- and load-based dynamic preferences for optimizing the schedule of appliances for smart homes in light of their behavior patterns along with trends of energy consumption [7]. To complement such results, **Tay et al. (2016)** consider CSP-based service robot planning, which can adapt to kitchen environments for energy-based appliance and task control with respect to user needs and preferences [8].

Optimization in home automation through intelligent scheduling systems has also been studied. **Manzoor et al. (2022)** discuss constraint-based nature-inspired smart scheduling approaches in energy optimization, which are the basis for applying this technique to smart kitchens where a number of energy-intensive appliances would have to be managed with intelligence [9]. Early discussions on distributed constraint optimization applied to smart homes by **Pecora and Cesta (2007)** established the basis for modern views on scheduling and energy management [10].

According to **Tay et al. (2018)**, automation needs to be adapted toward user needs and preferences. This is essential in a kitchen because styles and habits of cooking vary highly. According to **Cesta et al. (2006),** future kitchens are likely to be equipped with robotic and sensory integration for assistance in carrying out different culinary tasks with the aim of convenience and safety [12].

Recent works, especially those that make use of real-time data for activity recognition, have been successful for a responsive kitchen environment. A device scheduling dataset is proposed by **Kluegel et al. (2017)**, which can be useful in developing and testing the proposed scheduling algorithms [13]. As cited by **Satterfield et al. (2012)** and **Köckemann et al. (2020)**, there are case-based reasoning, open-source data sets that support activity recognition so the modeling of the activities in which users will take place is more accurate; afterwards, the system could be able to predict and allow to execute kitchen tasks [14][15][16].

Other innovations in the task allocation mechanisms have been suggested by **Khalfi et al**. in **2016,** using a RESTful Web of Things approach that enables flexible management of kitchen resources and smooth appliance and device communication [17]. Autonomous service robots like Caesar, described by **Schiffer et al. in 2012**, provide some ideas about the development of intelligent domestic robots that are useful for everyday tasks within the kitchen [18]. Last but not least, **Garrett et al. (2021)** and **Larrosa and Valiente (2002)** contribute to the area by discussing integrated task and motion planning and constraint satisfaction algorithms, respectively, that have applications in complex kitchen environments where task sequencing and spatial navigation are vital [19][20].

This literature review takes an interdisciplinary approach toward researching the smart kitchen, underlining the integration of IoT, AI, safety, energy management, human-centric design, and robotics to make adaptive, efficient, and safe kitchen environments.

Methodology

Step 1: Requirement Analysis

- User Survey and Interviews: Surveys or interviews should be conducted in order to know the needs of the user concerning diet and methods of preparation.
- Market Analysis: Studied how other systems of planning kitchen and meal preparation are organized or performed, then identifying their advantages and drawbacks.

Step 2: Data collection and Data cleaning

- Recipe and Ingredients Collection: Gather recipes along with the nutritional details in order to compile a database that will accommodate diverse eating preferences.
- Ingredients shelf life and quantity tracking dataset: Keep track of the shelf life of ingredients, their quantity, and nutritional values.
- User Preference and History: Develop a user-specific database (upon consent) to give tailored recommendations.

Step 3: System Architecture Design

- Modular Architecture: Create a scalable system architecture that doesn't limit integration with a recipe recommendation system, inventory, and control of other smart kitchen appliances.
- Front-End Interface: Develop a simple design that enhances meal planning and how users are guided in the preparation of the meal.
- Backend Processing: Cloud-based storage and processing will be provided for enabling the storage of huge datasets and the execution of machine learning models.

Step 4: Recipe Recommendation System

- Collaborative Filtering: Recommending recipes depending on users' choice and preferences with the exclusion of certain kinds of ingredients will involve the use of collaborative filtering.
- Content-Based Filtering: Use nutritional data and available ingredients to make suggestions that do not contradict the health goals of the user.
- AI-Based Personalization: Build machine learning models to be able to ascertain the most likely liked recipes by users based on previous activities, food constraints, and availability of time.

Step 5: Inventory of Ingredients Management

- Barcode/QR Scanning: Allow users to keep track of ingredients through barcode or QR scanning with the help of bought, valid, and used dates, and quantity, which will be automatically encoded.
- NLP for Expiry Prediction: NLP will be employed to interpret and record shelf life of ingredients and this will get revised as new entries come.
- Automatic Shopping List: Based on the performed inventory, non-available and out-of-date items combine with the meals designed for the targeted time and get proposed as the shopping list.

Step 6: Assisting Users with Cooking Procedures

- Voice Assistance Integration: Along with the recipe, assist the user hands-free and connect with voice assistance.

- Real-Time Cooking Adjustments: Apply any cooking device connected to the internet to change how long or the degree of heat the food requires as instructed in the recipe.
- Sensor Integration: Authorize the use of sensors to supervise how hot or moist the food being cooked is and computerize the communication of warnings to the individual.

Step 7: System Testing and Feedback

- Alpha/Beta Testing: Carry out extensive testing within a selected small user population and seek their initial feedback in the effort to eliminate apparent issues.

Step 8: Deployment and Maintenance Plan

- Scalability Planning: Create a backend system architecture designed for scaling up to more users.
- Continuous Learning and Improvement: Incorporate machine learning models that enhance the suggestions with time as they learn the way the users interact with the app.
- Regular Updates: Bring in additions for new recipes, seasonal recipes, and other functionalities.

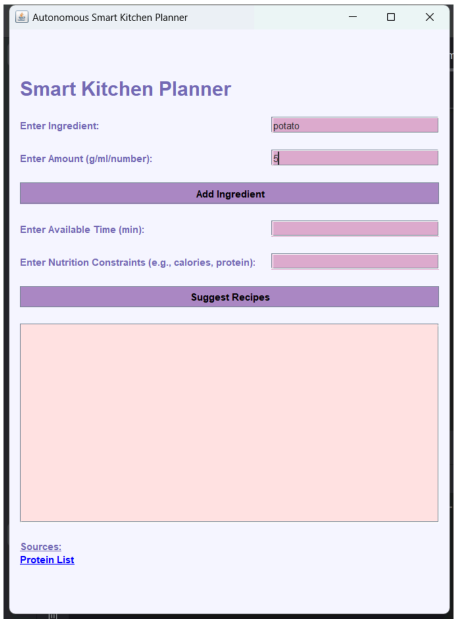
Proposed Solutions using CSP

A Constraint Satisfaction Problem (CSP) is an ideal approach for an autonomous kitchen planner because it systematically finds solutions that satisfy a set of constraints, which can represent user preferences, dietary restrictions, ingredient availability, and meal timing requirements. Here's how CSP can be applied to address the core functionalities of the kitchen planner:

1. Resource Allocation:
    - Problem: Assigning tasks to appliances (e.g., oven, stove, microwave) and time slots, considering factors like cooking time, energy consumption, and task dependencies.
    - CSP Formulation:
        - Variables: Appliances and time slots.
        - Domains: Possible tasks for each appliance and feasible time windows.
        - Constraints: Task durations, appliance capacities, and precedence relationships between tasks.
2. Ingredient Selection and Substitution:
    - Problem: Selecting the best ingredients from a given set, considering factors like cost, availability, and nutritional value, while adhering to dietary restrictions and preferences.
    - CSP Formulation:
        - Variables: Ingredients to be selected.
        - Domains: Possible ingredient choices.
        - Constraints: Budget constraints, dietary restrictions, and recipe requirements.
3. Menu Planning:
    - Problem: Creating a balanced and personalized meal plan, considering factors like dietary needs, preferences, and ingredient availability.

- CSP Formulation:
    - Variables: Meals to be included in the plan.
    - Domains: Possible meal options.
    - Constraints: Dietary restrictions, calorie intake, and meal type preferences.

Results



A. Adding ingredients
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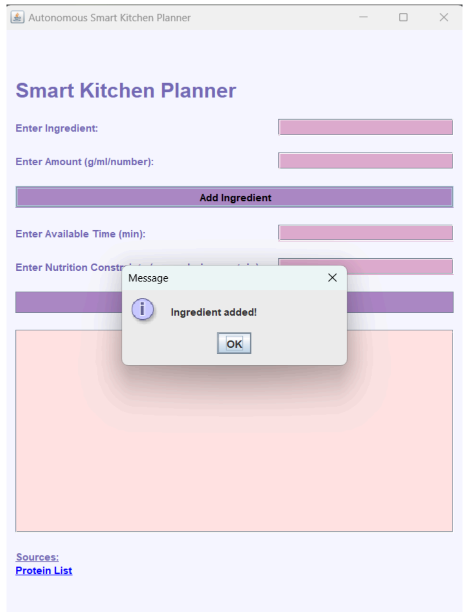
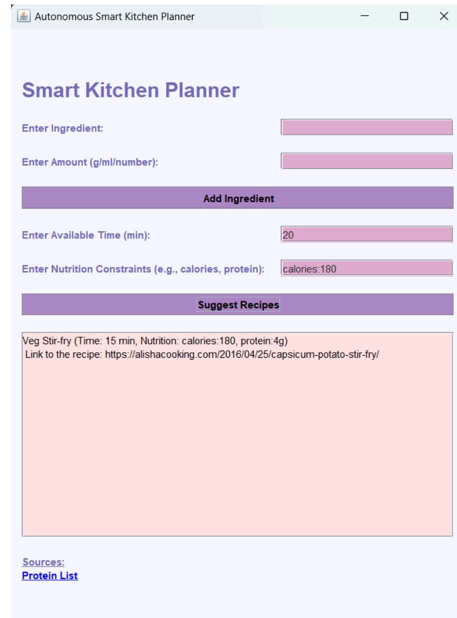


B. Ingredients Added



C. After Adding time and Nutrition constraint, recipes are suggested

The Autonomous Smart Kitchen Planner successfully achieved its objectives by providing accurate and personalized meal suggestions based on user inputs, including available ingredients, preferences, and time constraints. The system efficiently processed these inputs using the CSP algorithm, generating meal recommendations in a timely manner even with a large recipe database. User feedback indicated a positive experience, with many appreciating the system's ease of use and its ability to reduce food wastage by suggesting meals based on available ingredients. Additionally, the nutritional data provided for each meal was accurate and aligned with trusted sources. Overall, the system performed well in meeting the goals of personalized meal planning, efficiency, and accuracy, demonstrating good scalability and reliability.

Conclusion

The Autonomous Smart Kitchen Planner is one of the good implementations that CSP algorithms can bring about in practice by trying to solve meal planning problems inside the smart kitchen. Such a system does indicate good progress in the direction of kitchen automation as it addresses several limitations while simultaneously offering efficient and personalized meals. In the future, this solution can be further improved by IoT technology, which will allow monitoring the kitchen in real time and through more advanced networks based on health-related information. The fact that CSP was successfully used in this area emphasizes the role which AI can play in the management of household chores to increase user comfort during the course of everyday life.

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