SmartDiet: A Personal Diet Consultant for Healthy Meal Planning

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Abstract

Effective personal dietary guidelines are essential for health management and preventing chronic diseases. The objective of this research is to achieve nutrient-balanced food recommendations for each individual, while considering individual's requirements at the same time. To reach this goal, we developed a location-aware interactive diet consultant named SmartDiet based on the multi-objective optimization. The proposed personalized diet planning approach not only translates nutrient recommendations into realistic dish choices, but also accepts feedbacks from users to fine-tune their meal plans. The results showed that daily nutrition needs can be fulfilled by the designated meals, and the interactive diet planning scheme helps a user adjust the plan in an easier way. The guidelines generated by SmartDiet are expected to potentially improve the overall health and reduce the risk of chronic diseases of individuals.

1. Introduction

Increasing chronic diseases and obesity are health problems in modern societies that create much economic pressure on individuals, patients, and the national health care systems. Take diabetes for example, it affects more than 285 million individuals throughout the world according to the World Diabetes Foundation, which corresponds to 6.4% of the world's adult population, and the number is expected to grow to 438 million by 2030, corresponding to 7.8% of the adult population.

Self-monitoring could be the single best behavior an individual can use to improve their health. Empirical studies also repeatedly demonstrated that individuals who monitor their daily food intake often lose more weight and effectively keep away from chronic diseases. Optimal nutrition intake, as one of the most important factors in self-monitoring, is thus become an important part of disease prevention and have the therapeutic potential. Exploiting computer technology, especially on a portable mobile platform, to solve the diet suggestion problem has thus become an attractive and challenging research topic in computer science and healthcare domain.

Unfortunately, existing systems and methods for diet control and suggestion are not totally satisfying and have some common limitations. First, most of the existing systems dedicate their efforts to monitoring the food intake or storing the food nutrition information, but rarely give the user an appropriate diet plan or suggestion immediately [5]. These user intake records can only help review user's inadequate diet habits, but are unable to provide a real-time diet guideline for disease prevention. Second, even with the provision of the diet suggestion, current nutrient-based recommendations merely follow some general guidelines and are not intended for individuals. The effectiveness of such a general-guideline-based recommendation remains questionable because of different characteristics in each individual. For different users, personalized dietary counseling is believed to be more effective than just general guidelines since it takes into account specific nutritional needs and individual requirements (e.g., low sugar diet). However, personalized dietary plan is often made manually. It is not only impractical to meet the real-time feedback requirement but also a time-consuming process for nutritionist to design a menu with complex constraints. The more nutrient constraints there are, the harder it is to manually plan a menu the individual will find acceptable. Third, there is no easy way for interaction between the diet planning system and the user. Users can only choose to accept or not accept the diet planning result from the current system, but is lack of the ability to fine-tune the suggested meal content and give their feedbacks to system.

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In this paper, we proposed the SmartDiet system, a mobile mentor which provides a nutrition-balanced diet suggestion for a user on a mobile device, to address the aforementioned problems. Figure 1 shows screenshots of the SmartDiet. A user can get the personalized meal suggestion and view the detailed nutrition information about food from the proposed system. SmartDiet also accept user feedbacks to fine-tune the optimization result for diet planning.

The rest of this paper is structured as follows. Section 2 reviews the related works. Section 3 elaborates the proposed method, including interactive diet planning by multi-objective optimization and smart input by image recognition. Section 3 discusses the experiments performed and the results obtained. Finally, Section 4 summarizes the conclusions of this work.

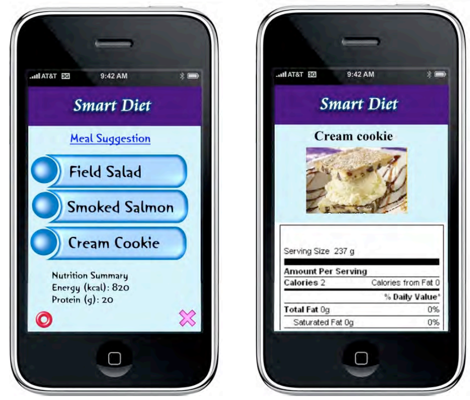

Figure 1. Screenshots of the SmartDiet. Users can get the personalized meal suggestion and check the nutrition facts of a food via the system.

2. Related Works

To achieve diet management and healthy diet, many non-commercial and commercial solutions have been proposed in the format of PC-based and smartphone-based apps to help users. The most often seen free resources on the Internet are calculators, questionnaires, food nutrient information system, and tracking tools. Calculators can help estimate user's current status according to some metric (e.g., BMI calculator), and evaluate the daily nutrition and energy requirement based on age, sex, metabolic rate and physical activity. Questionnaires (e.g., RealAge [8]) test a user's diet preference, exercise habits, and social connection to give a risk evaluation for various diseases and improvement recommendation. Nutrient information system and tracking tools aim at enabling users to monitor their progress in dietary and exercise habits over a special time frame. Many applications are also developed on the iPhone AppStore and Android Markets, such as Daily burn [1], Calorie Tracker, Eat This, Not That, and Nutrition Menu to name a few. These apps can be summarized as store and track what you eat and graph for reviewing a user's goal. However, none of the aforementioned tools or apps can give a user a personal guidance about diet management.

As to academic researches and patents, most previous works focus on developing a system that can help store user's intake or query nutrition facts of a food in a manual fashion. In [5], Shaobo Kuang et al. proposed a portable electronic device, which allows the user input a nutrition facts data about the food he or she takes into the device. The device then stores the nutrition facts a user takes, and possibly gives a warning message when the user takes more nutrition facts than the predefined thresholds. In [7], a cellular phone-based nutrition that can provide nutrition information to an end-user corresponding to the menu of a specified food service provider was developed. However, these methods cannot give any customized diet suggestions to users. Angell et al. [1] built a meal database indicating which foods are known to be helpful for certain diseases according to the latest medical studies. A meal plan is then identified for the set of prospective guests based on the collecting historical attendance data and a calendaring application. Unfortunately, Angell's system can only provide user the meals stored in the database, but not a customized diet, which considers user's personal requirements, for each individual. Mault et al. [6] proposed an image-based diet logging system, which assists a person create an image record of food items consumed by the person. However, all the user can do on the system is simply viewing the food images on the display of the electronic device and identifying food items consumed.

3. SmartDiet

The focus of this paper is creating a tailored menu that meets the needs of an individual. In this section, we will elaborate the proposed SmartDiet.

3.1 Overview

Figure 2 shows the block diagram of the proposed SmartDiet system. In the first steps, the system receives the geographical coordinates from the user's mobile device and negotiates with food providers adjacent to user's current location for acquiring available meals and the corresponding nutrition facts. The collected information is delivered to the next component. In step 2, the meal planner then solves the

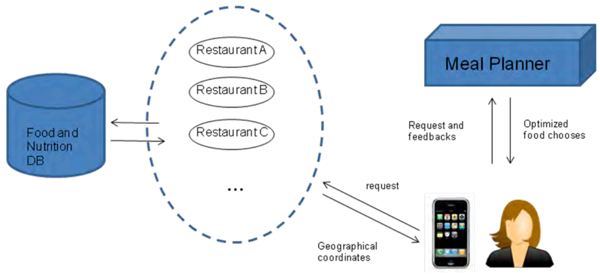

Figure 2. Block diagram of SmartDiet.

multi-objective diet selection problem according to its knowledge engine, which stores the nutrition constraints for different subjects (e.g., normal people or diabetic patients), and the historical intake data, which records the user's historical diet habits. Once complete, a combination of available dishes and restaurants that satisfies the daily nutritional requirements and user's current locality will send to user. In step 3, users can also interact with the system to adjust the recommended meals for meeting their personal requirements. In step 4, the proposed system will then update the constraints (e.g., the number of pasta must be at least 1) to give a customized diet plan according to user's selection. To achieve a better diet plan that can capture user's favor well, user can iterate from step 2 to step 4 until he or she find an acceptable food combination.

3.2 Meal Planner

Mathematically, the diet planning (or food recommendation) can be formulated as a multi-objective optimization problem, where the fundamental objectives are to meet the daily nutrition requirements. However, tailoring a menu to the needs of an individual requires not only the satisfaction of multiple numeric nutrition constraints but also the personal requirements. We thus develop Meal Planner, which tries to find the decision variables $\vec{x} = (x_1, x_2, \ldots, x_n)$ (i.e., the quantity of each available food) based on these factors, to give a customized meal plan.

3.2.1 Objectives

Considering the nutrition needs and user requirements, we have the following objective functions:

- Nutrition goal

The nutrition goal is to find a food combination that comes as close as possible to the expected daily nutrition requirements recommended by Dietary Reference Intakes (DRI) [1]. Assume that there are n different kinds of food and m different kinds of nutrition element in each food, we can have the nutriment element matrix as follows.

$$\begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} = \begin{bmatrix} e_{11} & \cdots & e_{1m} \\ \vdots & \ddots & \vdots \\ e_{n1} & \cdots & e_{nm} \end{bmatrix} \tag{1}$$

where f_i denotes the *i-th* available food in the area adjacent to user's current location, and e_{ij} denotes the *j-th* nutrition element in food f_i.

Let E_j be the expected *j-th* nutrition element per day, the generally accepted goal for nutrition will be to minimize the difference between the designated meals and DRI, which can be defined as

$$h_j(\vec{x}) = \sum_{i=1}^{n} x_i e_{ij} - r_k E_j \tag{2}$$

where r_k is the weighting of *k-th* meal (e.g., Breakfast, Lunch, or Dinner) and is used to give different emphases of a specific meal. Here we follow the nutrition guideline and have $\{r_1, r_2, r_3\} = \{0.4, 0.4, 0.2\}$.

- Budget goal

One important issue for personal meal selection is the price of dishes. If user has budget concerns and prefers food with lower cost, the budget goal can then help prevent the system from choosing luxurious food. To minimize the cost, the budget goal can be defined as

$$b(\vec{x}) = \sum_{i=1}^{n} p_i x_i \tag{3}$$

where p_i is the price of the *i*-th food.

- Meal favor goal

Different people have different favor in meal. For example, some might prefer dessert rather than main dish. In this case, we can introduce the meal favor goal to force the Meal Planner to select as much user's preferred food as possible. Similar to budget goal, we can define meal favor goal as $m(\vec{x}) = \sum_{i=1}^{n} r_i x_i$, where r_i is the rating of the *i*-th food and the score can be assigned by users in advance.

3.2.2 Constraints

Constraints are introduced to ensure that designated diets met various expectations. Here we include the following restrictions to ensured nutrient adequacy, food availability, meal diversity, and diet palatability.

- Nutritional constraint

Nutritional constraints defined nutrient levels for each nutrient in each diet. Here we use a threshold to set the standard nutritional constraints and give a balanceable nutrition meal, such as

$$r_k E_j - thr_j \leq \sum_{i=1}^{n} x_i e_{ij} - r_k E_j \leq r_k E_j + thr_j \tag{4}$$

where thr_j is the variable to determine the upper and lower bound of the difference between the exact *j-th* nutrition element and DRI.

The nutritional constraints vary if some other personal or disease requirements are provided. For example, patients who have diabetes cannot eat food containing too much glucose or users who want to loose weight prefer consume foods with low calories. In this case, the carbohydrate or calories intake would be lower than the standard nutritional constraint.

- Diversity constraint

A meal has to include a diverse set of foods from different food categories (e.g., appetizer, salad, main dish, dessert and snack) rather than totally from a single category. Diversity constraint thus placed an upper limit on the quantity of each food variable in the same food category, which is defined as

$$\sum_{i \in FC_k} x_i \leq 1 \tag{5}$$

where FC_k is the *k*-th food category.

- Location (food provider or restaurant) constraint

Diet planning should also consider the availability of foods. A decision variable x_i will be 0 if the food is not available around user's current location, where the locality information can be easily collected by location-aware negotiator.

3.2.3 Optimization Solution

The weighted-sum method [10] is employed to get a Pareto optimal solution for the multi-objective diet planning problem. The weighted sum method, which is one of the aggregating methods, allows the multi-objective optimization problem to be cast as a single-objective mathematical optimization problem, which is

$$\min \quad \sum_{j=1}^{m} w_j h_j(\bar{x}) + \alpha b(\bar{x}) + \beta m(\bar{x}) \tag{7}$$

subject to constraints

where w, α, and β are weights of each objective function, and normalization is considered to balance the different magnitude in different objective functions. After acquiring the aggregate objective function, convention integer programming solver such as branch and bound can then help find an optimal solution.

3.3 Feedback for Personalized Meal Planning

Since user may not be totally satisfied with the initial diet suggestion from Meal Planner, the SmartDiet thus allows the user to interactively fine-tune the menu. In this case, the user can choose to delete foods from and add foods to the menu, and the Meal Planner then recalculates a Pareto optimal solution based on the updated constraints. This interactive diet planning mechanism is therefore expected to provide the user a more customized meal plan.

4. Discussion

We collect foods data from USDA National Nutrient Database [9], FDA Taiwan, and menus on the Internet to serve as the food database, and the foods are organized in different food groups (e.g., appetizer or salad) and type (e.g., western style or Chinese style). An example of the meal planned by SmartDiet is shown in Table 1, where the menu was optimized considering the specific constraints in Table 2. As we can see the planned menu meets all constraints, including the nutrition requirement and user's preferred restaurant adjacent to user's current location (e.g., a western-style restaurant). The SmartDiet outperformed professionals in terms of time and quality. The proposed system needs from seconds to minutes for designing well-balanced optimal multiple-days menus, while it takes an experienced nutritionist or dietician hours to manually plan a daily menu for an individual or a group of individuals.

The user may still want to experiment to find an even better menu. For instance, the user might like to have a chocolate vanilla after his main course. In this case, the user can just take a picture of the chocolate vanilla on the menu to add this item, and the SmartDiet will automatically find another well-converged and well-distributed Pareto-optimal front based on the updated constraints (i.e., the quantity of chocolate vanilla need to be 1). As we can see in Table 3, the SmartDiet would find that fat and calories rise to unacceptably high levels after adding the chocolate vanilla into current diet plan. In this case, a new diet plan is interactively provided to meet the updated constraints, where Fruit Combo and French Fries were removed, and Strawberry Field Salad was substituted by House Salad.

Table 1. An example of initial diet planning result

Food name	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)
	260	4	7	30
French Fries	140	2	8	14
Shrimp Key West	225	23	7	4
Fruit Combo	250	3	0	10
Total	875	32	22	58

Table 2. Constraints

Food provider	Western-style restaurant in user's location		
Type	Lunch (r_k=0.4)		
Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)
2500	80	55	320

Table 3. Refined diet planning result

Food name	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)
House Salad	240	0	0	0
Shrimp Key West	225	23	7	4
Chocolate vanilla	400	7	9	65
Total	865	30	16	69

5. Conclusions

In this paper, we introduce the SmartDiet for diet planning. The system addresses the challenge of improving self-efficacy of self-monitoring of nutrition intake, personalized diet suggestion, and user compliance. The proposed Meal Planner, which automatically presents a user a combination of dishes and restaurants that satisfies the daily nutritional requirements and user's requirement, is leveraged for individual diet management and recommendation. In addition, the optimization result can be fine-tuned via user's feedbacks. With a user-friendly interface, user can practice a healthy diet with only a limited understanding of the nutriology and dietetics since SmartDiet can translate nutrient recommendations into realistic individual food choices. Patients will also be notified once they have improper diet or take the wrong foods. The SmartDiet can also help doctor or nutritionist to better take into account individual requirements while establishing dietary guidelines, which could improve the compliance of users and patients.

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