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輔助健康烹飪的智慧型廚房之使用者介面設計

Designing User Interface for Health-aware Cooking in a Smart Kitchen

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摘要

烹飪於生活中扮演了關鍵的角色，因為烹飪對健康來說非常重要。我們應用了 Ubicomp 技術提升家中廚房的功能，以幫助煮飯的人在烹飪過程中了解相關的健康資訊。在這篇論文中，我們敘述了這個廚房的循環設計過程。我們提出的智慧型廚房內建了感測器，用以偵測各種烹飪動作，並即時提供健康相關的資訊供使用者參考。這篇論文提出了數個應用 Ubicomp 技術至廚房的原型介面設計，評估這些設計的使用限制，並歸納出應用 Ubicomp 技術至如廚房等日常生活環境的設計建議。

Abstract

Cooking is an essential daily life activity because of its importance to good health. This study describes an iterative design process for augmenting a home kitchen with Ubiquitous Computing (UbiComp) technology to raise the health awareness of family cooks when preparing meals. The proposed *smart kitchen* has sensors for tracking cooking activities and provides real-time health-related feedback to family cooks. This study explores various prototype interface designs for integrating UbiComp technology into a kitchen, evaluates their limitations and identifies the design implications of applying UbiComp technology to everyday living environments such as a kitchen.

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Chapter 1

Introduction

1.1 Problem and Solution

Cooking is an essential activity in daily life because of its importance to good health. Researchers have identified many health consequences of poor diets such as excessive caloric intake and nutritional imbalance, which often increase the risks of chronic diseases [32]. For many family cooks, whether a meal is tasty is as important as its nutritional value. However, few family cooks know how to cook meals which are both tasty and healthy due to their lack of nutritional knowledge, their confusion over dietary guidelines [5] and the extra effort required to calculate nutritional value during the cooking process. Therefore, family cooks are often reluctant to expend time and effort on examining and changing their everyday cooking styles.

Based on studies done by Fogg *et al.* [12], a commonly used persuasive strategy to motivate behavior change is called “Reduction Technology”. It is about applying digital technologies to make a complex task, such as healthy cooking, simpler; therefore, it persuades users to perform the desirable behavior, i.e., healthy cooking, by increasing the “benefit/cost ratio” of the behavior. Additionally, a study by Bandura *et al.* [1] brings out the challenge in persuading users to perform a complex task. It states that overwhelming amount of efforts and time to learn and perform a complex task may cause users to regard themselves as lacking the knowledge and skills needed to perform the task. Based on their studies formulates our approach to motivate healthy cooking in family cooks - by increasing the accessibility of health-related information to family cooks, our system can raise their confidence and willingness to engage in healthy cooking.

1.2 Opportunity for Ubicomp Technologies

Ubiquitous Computing (UbiComp) technology provides an opportunity to overcome some of the obstacles to healthy cooking by applying health-related information from books, websites and health education classes to the actual cooking process. Additionally, using UbiComp technology to automatically sense and track cooking ingredients enables cooks to focus on cooking activities with fewer interruptions and acquire nutritional knowledge at the same time. This study hypothesizes that, by simplifying access to health-related information, cooks may be encouraged to follow the dietary guidance and pay more attention to enhancing the nutritional value of their meals.

1.3 Design and Implementation

This thesis presents the design and implementation of a smart kitchen which would provide family cooks with nutritional guidelines when preparing meals. The smart kitchen is embedded with sensors for detecting various cooking activities such as by indicating weight changes on the counter and stove. The software system includes a nutrition tracker that recognizes cooking actions based on detected weight changes of food ingredients used during cooking and a user interface for displaying real-time health-related feedback to raise awareness of the nutritional values of foods. For instance, when a user prepares a meal, the kitchen presents related information whenever it detects cooking actions that change the weight of food ingredients on the kitchen counter or the stove, such as adding meat, pouring in oil, etc.

1.4 Design Process and User Studies

The iterative design process resulted in three prototype interfaces, each providing different information based on an identical hardware design and activity inference engine. For each prototype interface, one user study was conducted in which experienced family cooks interested in healthy cooking participated in evaluating the effectiveness of the system in encouraging healthy cooking. How the cooks interacted with the UbiComp kitchen was also analyzed. The results of each user study were applied to refine the next prototype.

Results of three user studies demonstrated the effectiveness of the smart kitchen in providing nutritional awareness to participating family cooks. Our findings also showed that by increasing awareness of healthy cooking, participating family cooks had adjusted their cooking practices more healthily.

Results of our user studies revealed one important limitation of the smart kitchen. Although the smart kitchen simplified user efforts in performing healthy cooking, it also complicated some aspect of the cooking process by requiring additional user effort on operating it during the cooking process. The reason for this addition user effort is due to certain technology limitations in recognizing complicated cooking activities (described in details in later chapters), thus additional user effort is needed to accommodate the system's shortcoming. Our user study results showed that such additional user effort and technology limitation may be impractical to users in an actual kitchen environment.

1.5 Design Implications

The findings of the user studies revealed design implications for augmenting everyday environments with UbiComp technologies. A home kitchen is a complex environment, in which the complexity comes from cooking activities of different users, e.g., experienced, inexperienced, or occasional family cooks, with different user needs, thus different benefit/cost ratios in using technologies. The benefit refers to the user-perceived value of support from the system, and the cost is the amount of user efforts in operating the system. Technologies should adapt to individual users to optimize their individual benefit/cost ratios.

Since family cooks differ in their needs in performing healthy cooking, the system should customize technologies to address their specific needs. For example, if an inexperienced family cook needs more help in performing healthy cooking, the system should apply complex sensing technologies to support their cooking activities; however, complex sensing technologies may be more prone to recognition errors thus demand additional user effort in operating and correcting the system. Since an inexperienced family cook can receive more benefit, he/she is willing to put up the additional effort in operating the system.

Since a kitchen is a complex environment in which cooks must perform multiple tasks simultaneously, the opportunities for technological support are immense, but effective interaction is a major challenge. Therefore, the results of this study provide valuable insight into applying UbiComp technology in everyday environments.

1.6 Contribution

This study makes the following contributions to the field. A prototype smart kitchen was designed to encourage healthy cooking by providing family cooks with real-time health-related feedbacks. The user study results showed that the smart kitchen raised the nutritional awareness of cooks and helped them to produce meals according to nutritional recommendations. The user study revealed design implications that can guide the application of UbiComp technologies in everyday environments, *i.e.,* UbiComp technology and human activity should complement each other.

1.7 Thesis Organization

The remainder of this thesis is structured as follows. First, the background and design considerations are introduced. Second, system design and implementation are described. Third, the iterative process for designing the smart kitchen interface and user studies of each prototype are presented. Fourth, the limitations of applying UbiComp technologies to a kitchen are discussed, and the design implications are stated. Finally, conclusions are drawn.

Chapter 2

Kitchen and Cooking

This chapter describes general interactions between cooks and kitchen equipment as well as the contextual inquiry of the study. These observations are used to clarify the major design considerations for the smart kitchen.

2.1 General Observations

Cooking is a complex multistage process which includes selecting, measuring, processing and mixing food ingredients. Heat is often applied to the mixture of food ingredients using various techniques to produce the final result. Performing activities in each stage requires the support of different tools and equipment designed for specific tasks. We describe how cooks utilize such tools to achieve the desired results of meals in the following sections.

2.1.1 Kitchenware

Without tools, the human body can only perform limited tasks. Although the human hand can perform highly precise tasks, many cooking activities require the use of specialized utensils. Kitchen gadgets have been developed to complement human ability in performing tasks required in the cooking process. For instance, the shape and material of a frying pan makes it ideal for holding food ingredients for heating and mixing; the sharp edge of a knife can cut food ingredients to the proper size specified by a recipe, and the capacity of a scoop is useful for transferring small amounts of spices or other flavoring ingredients.

In addition to supporting cooks physically, some gadgets are designed to augment mental processes. Humans can apply only limited mental resources to performing tasks. Mental overload can be dangerous in a multitasking environment, particularly in a kitchen. Kitchen gadgets designed to moderate mental overload can reduce complexity by automating tasks according to instructions from cooks.

To reduce the complexity of tasks, gadgets allow cooks to retrieve status-related cooking information more easily, such as frying pan temperature, amount of food ingredients and volume of liquids. They can help to convert abstract properties into concrete renditions to facilitate quick measurements and comparisons. The scales on a measuring cup, for example, represent a vague concept of volume in a clear value. Thus, a visual indication of liquid measurements may be helpful. When performing automated activities, gadgets can execute designated tasks in accordance with the intentions or instructions of cooks. For example, a timer can be set to alarm the cook after a specified time period. By shifting the time counting task to a timer, a cook can switch to another task requiring full attention and switch back to the original task when the timer rings.

2.1.2 Appliances

Kitchen appliances are intended to assist in cooking activities. Many kitchen appliances are used to perform tasks like chopping, mixing or heating food ingredients, which tend to be highly repetitive and laborious. To increase efficiency, modern appliances have enhanced their original designs and have become more useful for performing complex tasks. A modern microwave, for example, may have several buttons on its front panel for different options, including defrosting, making popcorn, and various modes of heating. Some advanced models even have separate buttons for commonly prepared dishes. After placing the food ingredients into the microwave, one can simply choose different modes based on preferences, food ingredients and recipes, and the microwave automatically produces the meal. On the one hand, while these smart appliances do improve efficiency, they may sacrifice some quality of the resulting meals. However, although appliances requiring manual operation are much more difficult to use, they enable more adjustment of cooking methods, procedures and preferences.

2.1.3 Cooks

The above technologies assist cooks in efficiently preparing meals given user preferences regarding taste, smell and color. An important consideration is whether the equipment can be used even by cooks with limited skills and experience. For example, most cooks have their own preferred equipment, especially knives. A chef said, "*I enjoy my own set of tools. I know how my knife operates. It has a different balance.*"[11]

Modern technologies have automated many common kitchen tasks. However, regardless of their technological sophistication, traditional cooking implements still require manual operation. Only cooks who fully realize the capabilities and limitations of their tools can achieve their desired results. For experienced cooks who are very particular about details and who use traditional tools to achieve precise results, cooking may be complicated and laborious. Inexperienced cooks can produce similar results using automated equipment if they know how the equipment operates. Restated, when using kitchen equipment, cooks actually externalize their intention to use them, and the produced results are highly dependent on their predictions. Misunderstandings between cooks and the automated equipment can lead to failure.

2.2 Contextual Inquiry

A four-day contextual inquiry was conducted to understand the cooking behaviors of four experienced family cooks (aged 28, 30, 58 and 65) in their home kitchens as they were cooking regular family dinners. During the cooking process, they were observed and videotaped then interviewed in detail about their cooking practices and their understanding of nutrition and calorie control. The findings are as follows.

Family cooks are often reluctant to modify their cooking practices, which they develop by trial and error or by observing and learning from other family members. Cooking is a highly individualized activity. Changing the particular cooking style of a user within a short period is difficult, particularly in very experienced family cooks. Therefore, even if they are motivated to prepare healthy meals, they may still choose to retain their original cooking styles because they prefer the familiarity of their own cooking styles.

Another concern is whether healthy cooking methods produce appealing dishes. Most subjects reported attempting to adjust their cooking styles in accordance with healthy cooking tips gleaned from newspapers or TV programs. However, a continuing concern was whether healthy cooking practice yield tasty meals. For example, although most were aware of the health benefits of reducing ingredients such as oil, sugar and salt, most deferred to family preferences. Most family cooks require substantial time and effort to apply healthy cooking practices in their own cooking styles. For example, cooks may prefer to alter their eating habits rather than their cooking methods. One subject said, "*To reduce caloric intake, I would rather eat less but use the same amount of oil.*"

Most subjects favored the idea of providing health-related information during the cooking process. However, most were concerned that "smart" devices would be overly distracting. For example, one participant said, *"In order to keep all dishes warm before being served, I cook multiple dishes at the same time."* This indicates that cooks are reluctant to add to the complex multitasking already required for meal preparation. The subjects suggested that the system should offer the flexibility to cook according to their own experience and preferences rather than requiring them to follow instructions.

Chapter 3

Design Considerations

To design a kitchen that encourages healthy cooking, the following five main design considerations were identified based on the observations described in the previous chapter: (1) *transparency* of operating the system, (2) *flexibility* to choose whether or not to use the nutritional awareness system, (3) *unobtrusiveness* to minimize distractions, (4) *glanceability* to improve effective display of information and (5) system aesthetics.

3.1 Transparency

To minimize the mental burden of operating the system, a tool should be designed with high transparency. A transparent tool/system disappears from users' focus so they can concentrate on the actual task at hand [24], which means that the status of the system is predictable and compatible with user habits.

Since cooking requires the coordination of different tools and cooks have to switch their attentions between the operations of these tools, the system should not demand excessive attention causing unnecessary intrusion to other concurrent cooking tasks and tools. Restated, the system should be operated like any other tool that supports temporary tasks when needed but fade into peripheral once the task is complete.

3.2 Flexibility

Since there is no standard procedure for cooking, or even for specifically healthy cooking, the system should enable high user autonomy. Cooking is often based on preferences and habits. If the system forces cooks to follow the recommended methods of healthy cooking, they may refuse to use it due to lack of familiarity while demanding overwhelming changes to their current ways of cooking. Therefore, the system should simply present passive feedback to raise the health awareness of users and provide them with the option to use the system.

3.3 Unobtrusiveness

The method of delivering the information should be subtle. Because the kitchen is a potentially complicated environment, cooks must handle multiple cooking tasks simultaneously. Introducing rich or excessive digital information may distract them from their current tasks. Interference in the cooking process may lead to cooking errors and may even be dangerous. Therefore, the system display should be designed to avoid requiring rapid change and excessive attention from users.

3.4 Glanceability

Glanceability is the effectiveness and efficiency with which a display device conveys information. The display should be designed with high glanceability to improve efficiency in grasping the intended information. Two factors related to glanceability in the smart kitchen are information complexity and visualization. To reduce complexity, the provided information should be clearly related to the current cooking action without redundancy. Information visualization should match the actual environment to minimize perception time. System status information would apprise users of the limitations and capabilities of the system and enable them to operate the system more precisely.

3.5 Aesthetic

Aesthetic designs are viewed as easier to use than less-aesthetic designs [18]. The system design must effectively address two barriers to healthy cooking: lack of familiarity with healthy cooking methods and lack of familiarity with interactive technologies. Therefore, the proposed system should mediate such barriers to enhance user accessibility.

Chapter 4

Hardware Design and Implementation

Based on the above design considerations, an initial prototype of the kitchen was proposed, and is presented in Figure 1 (a). The smart kitchen includes the following two components: (1) a nutrition tracker that tracks the nutrition, composition and position of food ingredients currently on the kitchen counter or stove and (2) an awareness display that provides health-related information about the ingredients and dishes mirroring the actual layout.

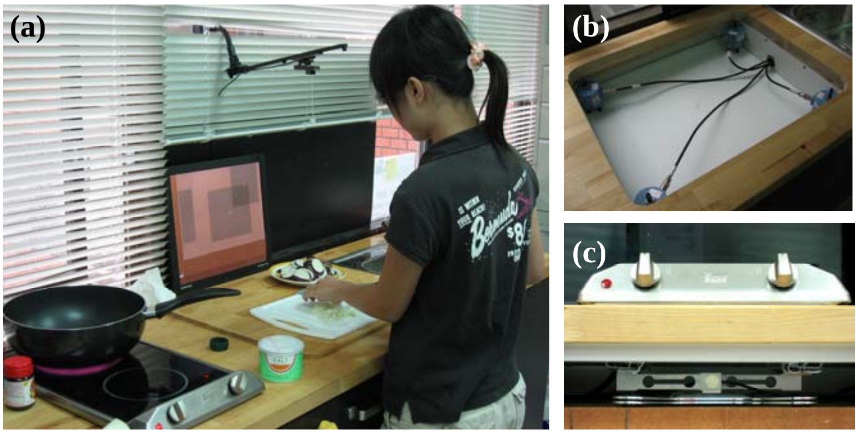

Figure 1. (a) Health-aware Kitchen with digital feedbacks of health-related information during cooking process. An overhead camera is deployed over the counter. Weighing sensors are deployed under counter (b) and stove (c).

4.1 Nutrition Tracker

Whenever a user performs a cooking action (adding or removing ingredients to or from a container) that may change the number of calories during cooking, the system must detect the cooking action in real-time. An example of such cooking actions is the addition of salad oil (130 kcal) to a pan or the removal of bacon (250 kcal) from a cutting board. Studies have shown that the nutritional values can be derived from weights of ingredients [23], and they are additive when composing ingredients. Therefore, to track nutritional values, the weight and the composition of food ingredients in dishes need to be determined.

Our nutrition tracker offers a hybrid sensing solution by combining weighing and camera sensing for accurate detection. Figure 2 depicts the architecture for cooking activity recognition based on hybrid sensing.

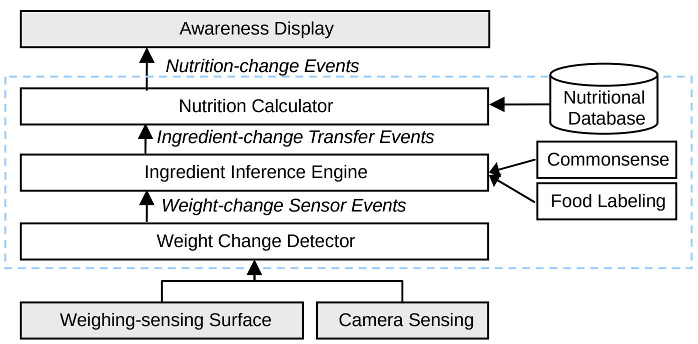

Figure 2. Nutrition tracker architecture.

4.2 Hybrid Sensing

To calculate nutritional values in food ingredients, we deployed a weighing-sensing surface in the kitchen. Based on our observations of cooking activities, most food preparation activities occur on the kitchen counter. They include putting ingredients on a plate, transferring foods among containers, cutting foods over a cutting board, mixing in a bowl and others. Hence, the system must accurately recognize the amounts (weights) of ingredients that are added to each container to calculate their nutritional values. For the prototype, the design was based on the load sensing table [25] in which four weighing sensors were installed at the four corners underneath the kitchen counter (see Figure 1 (b)). All foods ingredients are assumed to be placed in or on kitchen containers (e.g., plates and bowls, cutting boards are also counted as containers here), rather than being placed directly on the kitchen surface. Hence, the smart counter can track the position of the containers on the countertop with an accuracy of 1 centimeter, and measure the weight of food ingredients in these containers. On the other hand, most cooking activities are performed on the stove, such as frying in a pan, so a weighing sensor must also be present under the stove (Figure 1 (c)). All of the weighing sensors are attached to weight indicators with a resolution of one gram, which output readings through a serial port at a frequency of eight samples per second.

Camera sensing using video analysis is employed to improve the accuracy by filtering noise from the weighing-sensing surface. Based on preliminary experiments, detection using only weighing sensors is not sufficiently accurate (recall of 54%, meaning 46 detections of noise per 100 weight changes), especially when cooking actions, such as cutting or stirring, generate lots of weight noise. Observations indicated that when these actions are performed, the cook performs similar motion of foods using hands and/or utensils. For instance, to cut bacon, the cook uses one hand to hold the bacon and the other hand to take the knife, cutting little by little. Therefore, video analysis using a color histogram comparison [16, 4] is performed to filter false detections from weighing sensors. We deployed an overhead camera over the counter to capture an overview image of the counter (Figure 1 (a)). By comparing histograms of two camera images captured at different times, it can reduce sensitivity to the motion of objects since unchanging objects differ only slightly in histograms, while a real weight change resulting in large change of color histograms can still be detected.

4.3 Cooking Activity Inference

Our cooking activity inference is based on an event-triggered system. First, the weight change detector detects Weight-change Sensor Events including weight and position, such as (50 grams, “position:(10, 50)”) by processing weight samples from weighing-sensing surface and filtered with camera sensing. Second, an inference rule engine infers ingredient transfer activities by tracking the path of each ingredient from a starting container (as when bacon is put on the cutting board) to an ending container which holds the final cooked meal. A weight matching algorithm similar to that in our earlier work [7] is adopted to track this transference. That is, by matching a weight decrease (such as from a food container on a counter) to a weight increase (such as in a pan on the stove), food ingredient transfer is inferred and an Ingredient-change Transfer Event such as (“container1”, “salad oil”, 50 grams) is sent to the nutrition calculator. Commonsense knowledge on cooking is added to enhance inference engine. For examples, boiling water on the stove produces constant water evaporation resulting in weight decrease, and clams include non-edible shells that have no calorie. Third, because of the difficulties of recognition using computer vision or RFID tags on raw ingredients, a Wizard of Oz method that involves one human observer’s manually inputting the name of an ingredient is currently used to identify new ingredients during cooking process. When the inference engine detects a new ingredient that cannot be inferred by weight matching, the camera captures an image which is then shows to a human observer to ask its name in the other display that the user does not see. A voice-dialog system is also tested to enable family cooks to identify foods using a voice input, for application in the subsequent stage.

Finally, a public nutritional database that provides the nutritional values of each ingredient is used by the nutrition calculator to calculate the nutritional values, based on the weights and the names of the ingredients [30]. A high-level Nutrition-change Event describes ingredients and their nutrition contained within a container, such as (“container1”, “salad oil”, 130 kcal). This value is reported to the awareness display to interact with the user.

4.4 Limitations

For every cooking event (adding/removing ingredients), the average response time is one second to show calorie information on the awareness display. Since our tracking method is based on weight matching, the nutrition tracker has a limitation that it cannot recognize concurrent or interleaving events, such as taking two dishes from a counter simultaneously and then immediately putting the ingredients into the pan on the stove.

4.5 Awareness Display

After the nutritional values in ingredients have been determined by the nutrition tracker, the system provides real-time feedback to increase the user’s awareness of nutrition LCD display on the wall in front of the user. We have created three prototype interfaces in the iterative design process based on the nutrition tracker. In the next chapter, we will describe the design, user study, and discussion of the three interfaces in detail.

Chapter 5

Awareness Display

This chapter describes the design, user study and discussion of the three prototype interfaces created in the iterative design process. For each prototype interface, the design rationale and conveyed information types are described. User studies are then presented to show how these interfaces evolved according to the findings of the user studies.

5.1 Prototype I: Nutrition Awareness

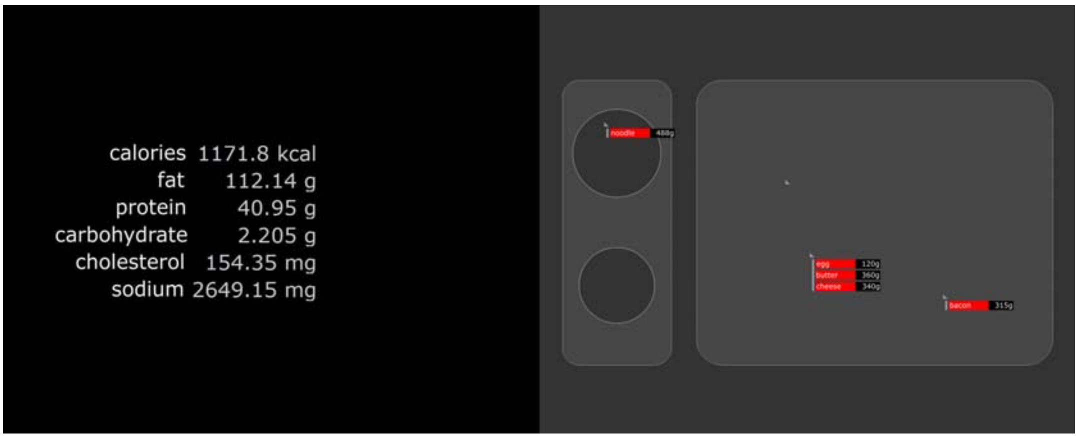

Figure 3. Prototype I.

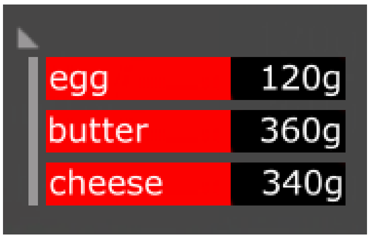

Figure 4. Graphical representation displaying a container with food ingredients and their weights.

5.1.1 Description

This prototype was created to investigate the feasibility of providing health-related information during the cooking process. As Figure 3 shows, the interface was comprised of two parts: an overview of containers and food ingredients in use, and detailed nutritional information. The right half of the interface displays information that corresponds to a layout of the kitchen counter and stove to provide direct mapping of the real environment. Containers on the counter are represented by small triangles at corresponding positions. Labels below the triangles show the names and weights food ingredients in each container (Figure 4). Adaptive information on detailed nutritional values of the most recently used container is shown on the left half of the display, including calories, macronutrients and other items related to common chronic diseases.

5.1.2 User Study

The initial solution was tested in a preliminary study. The objective was to observe how cooks would react to the provided information and how they would interact with the system during the cooking process. One experienced household cook was invited to use the system to cook four main-course servings of spaghetti in the laboratory using the following recipe:

Slice bacon into small strips. Heat the oil in a deep skillet over medium flame. Add the bacon for about 3 minutes until it is crisp and the fat is rendered.

Cook spaghetti in a 6-quart pot of boiling salted water until al dente.

While pasta is being cooked, beat together 4 eggs, whipped crème (315ml), cheese powder (50g), bacon from step 1, and 1/4 teaspoon salt in a small bowl.

Drain spaghetti in a colander and then pour egg mixture into the pasta in a pot, then toss with tongs over moderate heat to combine. Serve immediately.

Since only one cook participated in this user study, the user results were limited to the initial findings and used to guide the development of the prototype.

5.1.3 Findings

Two features in this version were direct mapping and adaptive information. Direct mapping was intended to minimize the time needed to perceive information. For example, when the system detects user actions, the resulting information is easily located at the corresponding position on the display. Adaptive information is designed to display the most relevant but detailed information to reduce perceived complexity. However, some user feedback indicated that the information was still difficult to interpret. For example, although the detailed nutritional values shown on the left half of the display provided accurate measures, the data was not perceived as useful and may have caused confusion. Further, some participants were uncertain what amounts of food ingredients were good or bad and had difficulty applying the information to improve their cooking due to the lack of recommendations. Additionally, the participants found it difficult to keep track of the total meal calories given that the awareness display showed only calorie count for the most recently used container. Some information, such as the weight values of food ingredients, were not very helpful, and the small triangle used to represent the container was easily overlooked.

Although several design flaws were noted, the system still proved effective for raising awareness of nutritional properties of food ingredients during cooking. For instance, one participant was surprised by the high calories in bacon and reduced the amount used. This suggests that real-time nutritional information increases awareness of nutritional properties of foods and enables cooks to adjust certain food ingredients.

5.1.4 Discussion

Although the direct mapping feature proved effective for helping users find information corresponding with their actions, the following refinements were identified for the next version of the interface.

- Detailed nutritional information should be simplified because users have difficulty comprehending and applying multiple aspects of nutritional information at a time [27].
- Recommendations should be provided to facilitate easy comparisons.
- Redundant information should be removed, and containers should have clear displays.

5.2 Prototype II: Calorie Awareness

Figure 5. Prototype II.

5.2.1 Description

The main interface gave an overview of the food ingredients and containers in use. Instead of providing nutritional details, the interface only displayed the number of calories in current food ingredients on the stove and counter to minimize visual complexity and to present information efficiently.

The reason for selecting calorie information was because caloric intake is a well-known health concept and is highly related to obesity, which is associated with many chronic diseases [32]. Controlling caloric intake can therefore benefit the most users.

Each container was represented on the interface as a rectangle, the size of which was determined by the actual size of the container captured by the camera. The information related to cooking and health, including total calories and specific ingredients in the container were displayed within the rectangle. Containers with higher calorie were represented with a darker color to notify users visually; therefore, users could consider whether to adjust their use of the ingredient. Various tones were used to gently inform users of changes in system status.

The vertical bar in the left part of the interface showed the current total calories of the meal currently being prepared. Also displayed on the bar for easy comparison was the recommended calorie count, which was determined using the Harris-Bendict equation [14] based on weights, heights and ages. Data for individual family members were inputted before using the system.

5.2.2 User Study

In this user study, we aim at two things. (1) How effective is the system in improving the family cooks' awareness on calories in food ingredients during cooking? (2) What cooking behaviors are affected by our kitchen?

An evaluation was performed to determine how the awareness of calories affects users. Since the activities in the cooking process are complex, rather than focusing on a specific behavior, a holistic view is taken to gather both quantitative and qualitative observations.

Participants

Three adult participants, P1, P2 and P3 (Table 1), were invited to participate in the user study. They were all experienced cooks of more than five years who regularly cook meals for their family members.

Participants	**P1**	**P2**	**P3**
Age	24	58	25
Gender	Female	Female	Male
Household size	4	3	4

Table 1. Profiles of participants and their family members.

Experimental Design and Procedure

Since our prototype kitchen was constructed in laboratory, it could not be easily moved to each participant’s home. Therefore, participants were invited to cook in the laboratory. A video camcorder was used to record the participants’ cooking sessions and their interactions with our system; their consent was obtained for subsequent analysis.

Our user study involved the following three phases: (1) pretest cooking without feedback on calories, (2) test cooking with feedback on calories, and (3) posttest interview. To compare the effectiveness of our smart kitchen between pretest cooking and test cooking phases, each participant was asked to write a fixed dinner menu (Table 2) as if they were to prepare a regular dinner for their family. P1 and P2 wrote a Western dinner menu, whereas P3 wrote a Chinese dinner menu. Based on their dinner menus, they were asked to prepare ingredients using our budget and bring them to our kitchen. Then, the three participants were asked to cook meals in the manner that they did at home, for a total of five cooking sessions per participant in one week. In each cooking session, each participant was asked to cook according to their designated dinner menu in our laboratory kitchen. The participants were given freedom to modify the ingredient composition of the courses (such as by changing the salad dressing, removing mushrooms from spaghetti), but they were not allowed to add a new course or replace an existing course (such as by changing a salad to soup). At the end of the cooking session, participants were free to take their cooked foods home.

In the pretest cooking phase, each participant cooked two meals on two separate days without turning on calorie feedback. Before the start of the first pretest cooking session, the three participants were given time to familiarize with various appliances and the arrangement of cooking tools in the laboratory kitchen.

Participants	**Menu**
P1	Salad (with apple, celery, and thousand-island dressing); Salmon; Fried aubergine with onion; Spaghetti (with bacon, mushroom, onion, and milk)
P2	New England clam chowder (from Campbell's Condensed Soup [6]); Bream roll with bacon with special sauce (including UHT whipped cream, onion, white wine, and lemon), rice and vegetables (cauliflower, carrot, and sweet corn); Salad (with lettuce and thousand-island dressing)
P3	Shrimp with scrambled egg; Mapo tofu (fried tofu with meat sauce and green onion); Asparagus with abalone; Chinese Clam Soup; Rice

Table 2. Menus designed by participants for testing.

In the test cooking phase, participants came to cook for another three meals on three separate days using the calorie feedback on the awareness display. Before the start of the first test cooking session, the calorie feedback interfaces were explained to the participants. The participants were also asked not to perform cooking actions outside the recognition limit of the calorie tracker, i.e., avoid performing concurrent cooking actions. Participants followed this rule with reminders in the first cooking session, and then were able to remember it. Later interviews with participants revealed that although following these rules lengthened the cooking time, it did not affect cooking style.

A posttest interview was performed on the final test cooking day and after the participants finished their last cooking session. They were interviewed about their experience of the kitchen with calorie feedbacks.

Measurement

To determine how effectively participants perceived and utilized calorie awareness information, this study first measured their meal calorie during five cooking sessions. Reduction in meal calories from pretest to test cooking phases suggested that bringing healthy cooking awareness through calorie feedback was effective. The method counted the number of calories in a prepared meal by subtracting the weights of all food ingredients at the end of each cooking session from that at the start of the session. Then, the nutritional database was used to determine the total calories in every meal. Second, the amounts of changes in the ingredients between the pretest and test cooking phases of each participant were analyzed to understand how participants utilized calorie awareness to reduce meal calorie during cooking.

Results

Table 3 presents the numbers of meal calories in each cooking session over five days. The two main findings are as follows. All participants reduced the number of meal calories from the pretest cooking phase (without calorie feedback) to the test cooking (with calorie feedback) by an average amount of (195, 688, 887) kcal. All participants cooked meals of calorie count within ±13% of the recommended amount, and the reduction of calorie used was up to 25.9%. Notably, participant P1 was originally aware of the amounts in use, so the calorie she used in the pretest was already around recommendation (2.8%). Participants P2 and P3 were lack of nutritional knowledge, and they cooked above the recommended amount during the pretest cooking phase (38.1% for P2 and 45.6% for P3). Therefore, the system herein helped them be aware of calories, and further the reduction of meal calories from pretest to test cooking phases was more significant, for P2 (25.9%) and P3 (22.4%) than for P1 (6.4%).

Participants		**P1**	**P2**	**P3**
(1) Recommended calorie		2,981	1,926	2,723
(2) Pretest	Day 1	3,070	2,677	3,951
	Day 2	3,058	2,641	3,976
	Average	3,064	2,659	3,964
	Over recommendation	2.8%	38.1%	45.6%
(3) Test	Day 3	2,937	1,916	3,308
	Day 4	2,780	2,099	3,027
	Day 5	2,890	1,897	2,896
	Average	2,869	1,971	3,077
	Over recommendation	-3.8%	2.3%	13.0%
(4) Reduction		195	688	887
(PretestAVG -TestAVG)	Percentage	6.4%	25.9%	22.4%

Table 3. Meal calorie (in kcal) during each cooking session.

We analyzed how participants changed their cooking behaviors to achieve calorie reduction. Our finding was that our participants were targeting high-calorie ingredients, in which a minor reduction in their amount leads to a significant reduction in the overall meal calories as shown in Table 4. For instance, in P1's meal, 61.2% of the total calorie decrease was from the oil. P1 planned to reduce the amount of oil when she found the calorie count was high, and thought it would help keep the number of calories under their required amount, while keeping the meal delicious. In P2's meal, 75.5% of the total calorie decrease was achieved by reducing the amount of condensed soup. P2 noted that the soup had more calories than she expected, and reducing the amount could greatly lower the calorie count while keeping the meal still tasty.

Finally, in P3's meal, 34.8% of the total calorie decrease was achieved by changing the amounts of meat sauce and tofu. He responded that he found "Mapo Tofu" contained too many calories, so he just used smaller servings to reduce the number of calories.

P1		**P2**		**P3**	
ingredient	**ratio**	**ingredient**	**ratio**	**ingredient**	**ratio**
oil	61.2%	soup	75.5%	meat-sauce	34.8%
spaghetti	16.4%	bacon	10.7%	tofu	26.0%
sauce	6.9%	buffer	6.2%	oil	19.3%

Table 4. Top three reduced ingredients associated with a total calorie decrease of more than 5%.

The findings of the posttest interviews are described below. P1 said, *"After perceiving this information, I would also consider the amounts of ingredients in my shopping."* For example, now I have ideas about buying the appropriate size of salmon (given calorie consideration), and I will be careful not to buy (food ingredients) beyond my calorie target." P2 stated that *"This kind of instant feedback is effective to remind me of what I already know about using the condensed soup and some high-calorie ingredients such as UHT cream."* P3 said, *"I'm glad to get this kind of calorie information without additional effort, because I should really be aware of using less of an (high-calorie) ingredient and not all in the whole package."*

Participants had the following expectations of the future direction of this kitchen: (1) they were interested in preparing a nutritional balanced meal, including appropriate servings covering all five major groups of foods (grains, vegetables, fruits, milk, and meat and beans). However, nutritional balance is difficult to measure, record, and understand. (2) They wanted expert cooking tips, during their cooking sessions, about healthy alternatives or substitutes for certain less-healthy food ingredients (e.g., olive oil as a substitute of butter) or cooking method (e.g., frying).

5.2.3 Findings

In this user study, all three participants successfully reduced their meal calories from pretest to test cooking phases, and the calorie counts of their meals approximated recommended amounts. Note that since this user study was conducted under laboratory conditions, the user results may differ for a smart kitchen in an actual home. Additionally, only three participants were invited to cook for a total five times. Thus, the user study should be considered as only a pilot user study lacking conclusive evidence.

The system encouraged family cooks to prepare healthy meals with appropriate number of calories by raising awareness of caloric values of foods during the cooking process. The effectiveness of the system was demonstrated by the reduced calories of meals actually prepared in the user study.

However, the reduction may not have been entirely due to the proposed system. Restated, choosing to reduce meal calories could not confirm that the participant had been persuaded to permanently adopt healthy cooking practices. The reason for the doubt is that participants may have viewed calorie reduction as merely a task required for the user study, which may partially account for the reduction. The participants chose to reduce their meal calories with the support of the system under experimental conditions and eventually succeeded in doing so. This observation indicates that the system provided sufficient support for them to complete the task but does not indicate whether they would continue doing so in actual practice. The actual long-term performance effects of the system can be realized only through an in-situ long term study involving more participants.

5.2.4 Discussion

For transparency and flexibility considerations, the system was designed to detect each cooking step in which food ingredients were adjusted and to display these adjustments for the user. A cook could choose to apply the provided information when preparing meals or simply ignore it, which was intended in the design of the system. However, one interesting observation was that, once the participants decided upon the amount of a food ingredient to use, they disregarded the latter information provided by the system and focused on processing the food ingredient. Performing food processing involves activities such as rearranging the containers on the counter to increase space, taking food ingredients out of containers and transferring food ingredients between containers. Although all these activities are continuously recognized by the system and are reflected on the display along with various sounds, users may choose to ignore them.

Since the objective was to support decision making processes regarding appropriate amounts of food ingredients, the current design of merely providing information about each container and its content was inadequate. When considering the amount of food ingredients to use, cooks determine how much of the food ingredients to place on the counter and how much to return to the refrigerator. This corresponds to transfer of food ingredients between the counter and the refrigerator, which is not tracked by the system, rather than between one container and another. Therefore, the system was further refined to assist the thinking process when making adjustments rather than passively indicating the cooking activities on a display.

5.3 Prototype III: Calorie Awareness with Nutritional Balance Information

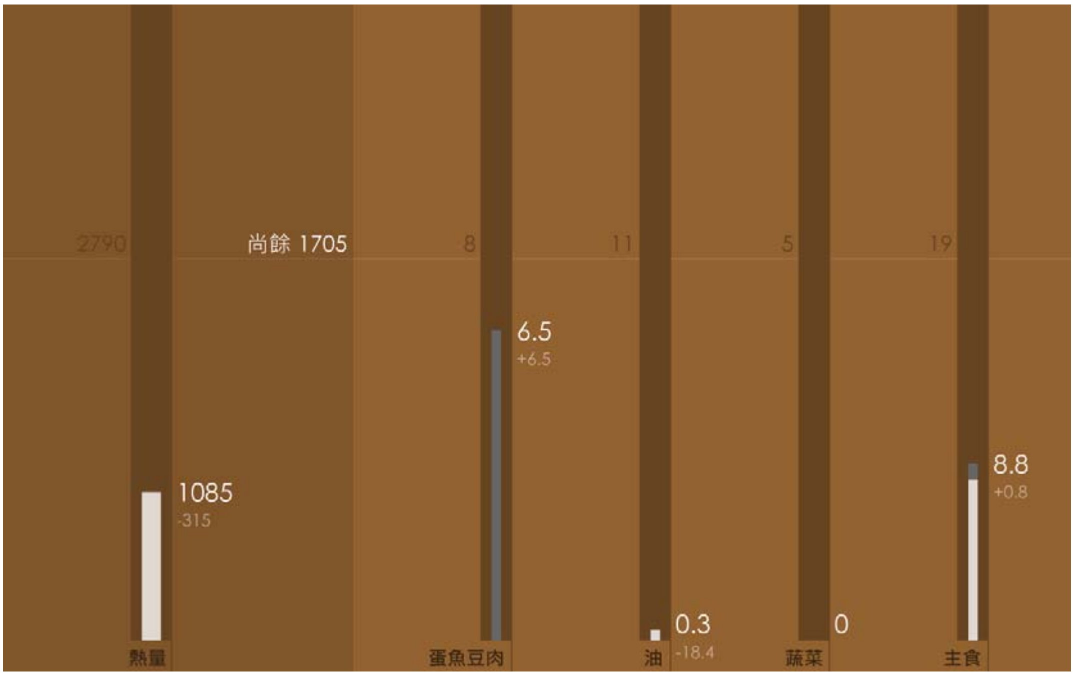

Figure 6. Prototype III.

5.3.1 Description

The prototype was modified to further enhance decision making during cooking. Therefore, the interface was modified to present all currently used food ingredients together on the screen rather than in individual containers. The observed problem that enhancing awareness of calories alone is insufficient for improving meals was also corrected by integrating the dietary guidelines of the USDA [29] (United States Department of Agriculture) into this version of the prototype.

For dietary guidance, food ingredients were classified into five categories: meat and beans, grains, vegetables, oils and fruits. These guidelines are not only helpful for determining daily nutritional needs, but also helpful for achieving a balanced diet of different food categories. A serving is a measurement unit representing a certain quantity of food ingredients. Different food ingredients in the same category with the same number of servings have similar nutritional values and can be used interchangeably when planning a meal. Thus, the guidelines are helpful for selecting food types needed for nutritional balance.

The interface consists of five bars. The bar on the left shows current calorie usage, which is the same as in the previous prototype. The right four bars display the food category of currently used ingredients in terms of servings. The recommended calories and food categories are calculated and displayed on the bars. Cooks can refer to the amount of each food category to achieve the recommended calories. If all food categories are within recommendations, total calories should be within recommendations as well. If the usage of a certain category exceeds recommendations, the cook may consider reducing items in other categories, based on personal preferences, to keep calorie count within the recommendation. Ideally, cooks would continually refer to the system to achieve the goal of appropriate caloric intake and nutritional balance.

5.3.2 User Study

In this user study, we aim at two things. (1) How family cooks use the system during cooking? (2) What is the learning effectiveness of the system?

Participants

To ensure that the participants in the user studied were highly motivated in healthy cooking, three adult participants, P1, P2 and P3 (Table 5) were recruited for the user study from a nutritional education class held at National Taiwan University Hospital. The nutritional education class from which they were recruited provided instruction in portion size of food ingredients for a healthy diet based on the dietary guidelines issued by the hospital. All participants had more than 30 years of experience in preparing regular family meals. Because P2 and P3 were couples, they cooked together in the user study.

Participants	**P1**	**P2**	**P3**
Age	57	63	58
Gender	Female	Male	Female

Table 5. Profiles of participants and their family members.

Experimental Design and Procedure

The participants were invited to cook in the laboratory once weekly for a total six sessions. All cooking activities were recorded on video for further analysis. After receiving a detailed explanation of the study, all subjects gave informed consent to participate.

The user study involved the following three phases: (1) pretest cooking without feedback, (2) test cooking with feedback, (3) posttest cooking without feedback, and (4) posttest interview.

In each cooking session, the participants were asked to prepare meals for their actual family members given considerations of calorie recommendation, which were determined by Harris-Benedict equations [14]. The participants were not asked to follow the recommendations exactly but rather to consider them during meal planning since some tradeoffs were expected during the meal planning process.

Many different food ingredients were prepared in advance by the authors, and the participants were allowed choose any of them for use in preparing their meals. The participants were also given the option to refer to materials from their current nutrition class. After the participants finished cooking, they were allowed to bring the cooked meals home.

The participants were informed that the system would be removed in the posttest cooking phase to determine the effectiveness of the system after using it three times. The participants were expected to become adept at estimating portion sizes of food ingredients after using the system. The participants received no information about their performance until they had finished all six cooking sessions to ensure that improvement was based solely on use of the system rather than on knowledge gained in previous sessions.

In the pretest cooking phase, participants cooked twice in two different weeks without providing feedback. This phase recorded the original performance of the participants, and enabled them to become familiar with the settings and appliances of in the kitchen. In the test cooking phase, participants cooked meals once weekly for three weeks and were given feedback by the system. Before the start of the first test cooking session, the feedback from the interface and the method of operating the system were explained to the participants. The limitations of the system were also explained. In the posttest cooking phase, participants prepared a final meal after the end of the test cooking phase without receiving feedback. A posttest interview was conducted on the posttest cooking day after the participants had completed their final cooking session. They were interviewed about their experience using the smart kitchen and then given reports on their performance during the five cooking sessions.

Measurements

Meal calories were measured during six cooking sessions of the participants. Reduced differences between actual meal calories and recommendations from pretest to test cooking phases suggested that the system was helpful in achieving meal calories within the recommendations. Learning effectiveness was also checked by comparing test and posttest cooking phases. In addition to quantitative measures, videotapes were also analyzed to determine how meal planning was affected by introducing the system and how the participants interacted with the system.

Results

Table 6 presents the difference between the recommendations and the prepared meal calories in each cooking session. In all subjects, the differences were larger in the pretest cooking phase (16.8% for P1, 80.8% for P2&P3) than in the test cooking phase (12.8% for P1, 46.3% for P2&P3), which suggests that the system helped them control calories. Without the aid of the system in the posttest cooking phase, the differences remained at the same levels (6% for P1, 42.8% for P2&P3), which indicates that the participants had become familiar with appropriate proportions of food ingredients through their experience using the system. The test results are explained in further detail below.

In the pretest cooking phase, the results of all participants were inconsistent, particularly those of P2&P3. These subjects tended to produce meals larger than the normal portion size in the second cooking session. They indicated that the calorie recommendation was higher than expected and therefore used more food ingredients than they would at home in order to achieve the goal based on their calculation. The inconsistent performance in the pretest cooking phase suggests that the participants were not familiar with the concept of considering calories when preparing meals.

Participants		**P1**	**P2&P3**
(1) Recommended calorie		820	835
(2) Pretest	Day 1	-155	182
	Day 2	123	1,168
	Average of ABS	138	675
	Percentage	16.8%	80.8%
(3) Test	Day 3	-123	250
	Day 4	-121	351
	Day 5	-71	560
	Average of ABS	105	387
	Percentage	12.8%	46.3%
(4) Posttest	Day 6	49	357
	Percentage	6.0%	42.8%
(5) Reduction		89	318
(PretestAVG - Posttest)	Percentage	10.8%	38.1%

Table 6. Difference between actual meal calories and recommendation (in kcal) during each cooking session.

In the test cooking phase, P2&P3 reduced the numbers of calories in their meals, but the calories still did not approximate the recommended calories as closely as those prepared by P1. The decision making process of participants regarding the amounts of food ingredients is unclear because the planning process was not observable, was related to many factors and changed in different cooking sessions. One explanation for the difference is the motivation of the participants. For example, P1 expressed an interest in learning healthy cooking by participating in this user study. During the experiment, she performed the planning process very carefully, which may explain her better results. Another reason may be the ambiguity resulting from the experimental design, which did not give the participants a clear goal to achieve. Thus, there was no clear basis of comparison.

All participants asked whether they could change the recommended ingredients since they could check their current performance with the support of the system. Our response was that the recommendation need not be followed exactly but should be considered when planning the meals because of the experimental design of the study. However, this design would produce ambiguity if they were asked to follow and disregard the recommendations at the same time. Participants P2&P3 indicated that they did not cook as usual since they would not use the recommended amounts of food ingredients when cooking at home. Further, they clearly did not cook according to the recommendations of the system either. A possible reason is that, although they attempted to comply with the recommendations, they did not attempt to do so as accurately as P1.

5.3.3 Findings

The results for P1 suggest that the provided information was sufficient to achieve the goal, but do not explain how the system encourages healthy cooking. The questions were the following: Would family cooks be likely to use the information? What determines the willingness of family cooks to use the system in support of their cooking? These questions are related to different benefit/cost ratios, defined in Chapter 1, between P1 and P2&P3. Because of her higher perceived-value on the nutritional support of the system as well as a stronger motivation to learn healthy cooking, P1 made more effort than P2&P3 did to prepare meals with the support of the system and in accordance with its recommendations. The inferior results of P2&P3 were due to their lower benefit/cost ratios than that of P1. Restated, P2&P3 did not value the system's nutritional support as high as that of P1; therefore, they did not want to spend the additional efforts in following the nutritional recommendation of the system. Therefore, in accordance with the original concept of overcoming difficulties of healthy cooking by simplifying the efforts, we should also avoid creating additional difficulties operating the system at the same time.

5.3.4 Discussion

During the user study, participants asked if they could turn the system off after they had finished measuring the food ingredients. One participant asked,*"Why bother to track the cooking activities if the goal is only to help deciding the used amount of food ingredients within the healthy level?"* He felt that a device that accepts manual inputs of food ingredients and calculates nutritional values based on the inputs before the actual cooking would be more convenient.

Recall that the original concept was a smart kitchen that encourages healthy cooking. The goal was achieved by progressive stages of the iterative design process, and the solution for each stage could be applied to solving the original problem. Thus, the problem varied from health-aware cooking, to nutrition-aware cooking, and then to calorie-aware cooking in the various iterations. These problems were addressed by different prototype interfaces with distinct health-related information such as nutritional value or calorie count, but the hardware design remained the same. However, the findings of this user study suggest that the system design may not be appropriate for the narrowed problems, and an inappropriate use of technology was noted. Hence, the solutions to the narrowed problem were limited to use in solving the original problem, which is discussed in detail in the next chapter.

Chapter 6

Reflection

This chapter reflects upon the findings from our user study reported in the iterative design process by asking the following questions: What caused the user behaviors observed in these findings? What are the meanings behind these findings? Recall that these user study findings were: (1) participants tended to ignore the system in later stages of cooking; (2) after performing meal planning, participants asked if they could turn off the system because they no longer needed the information; (3) the performance of participants differed when using the system.

Through an interpretative process, we sort out the following points that help explain these findings and identify the potential problems in our smart kitchen:

- Evolving problem scope and design goal during the iterative design process
- Limited time usage of technology
- Technology limitations and benefit/cost ratios

These points represent three aspects: design, technology, and user. The relationship of them is shown in Figure 7, which is discussed in further details in the following sub-sections.

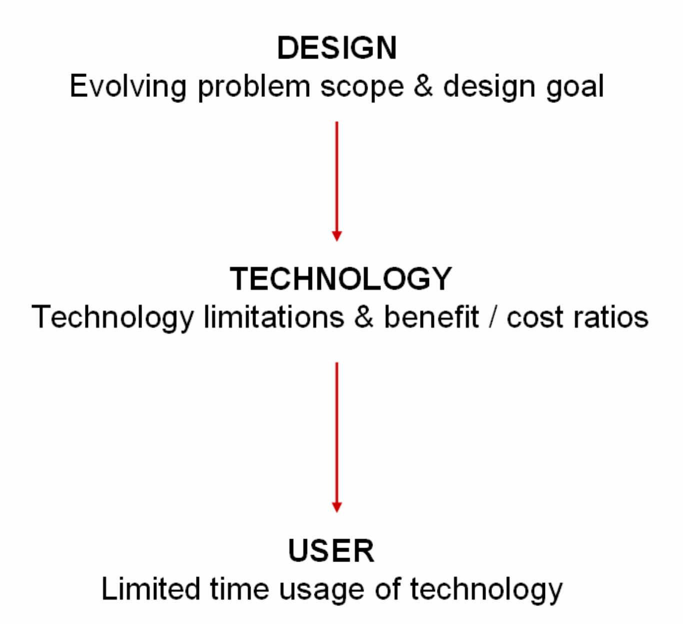

Figure 7. The relationship among the design, technology, and users.

6.1 Evolving Problem Scope and Design Goal

Our initial conception was a smart kitchen that encourages health-aware cooking by suggesting amounts and types of food ingredients as well as advice on cooking methods. To make this possible, technology was designed and implemented to automate or semi-automate the detection of different cooking-related activities performed throughout the cooking process. To meet the design considerations of transparency and flexibility, our approach was embedding UbiComp technology into a kitchen to provide nutritional information and automated assistance while allowing cooks to concentrate on their primary tasks of cooking.

In the iterative design process, both the problem scope and the design goal evolved (i.e., narrowed down) from providing health advices during the entire cooking process to helping decisions on the types and amounts of food ingredients. This evolvement was partially due to the user study findings, in which most family cooks expressed that they do not know how to decide appropriate amounts of food ingredients. Thus, based on the same hardware design, we developed the nutrition-aware version and a further calorie-aware version of the smart kitchen, in which they only analyze amounts of food ingredients, which is much easier to detect, and beneficial to users. The solutions to these sub-problems were expected to help solve the original problem after improving the sensing and AI techniques. Three prototypes were developed to address different problems based on the same solution designed for the original one. This simplification was crucial to this study and is revisited below.

6.2 Limited Time Usage of Technology

In the user study of the second prototype, the participants tended to ignore the system in certain conditions, especially in later stages of the cooking process when the provided information was irrelevant to current activity or redundant, e.g., transfers of food ingredients from one container to another container that do not result in any change in meal calorie. To address this problem, the third prototype enhanced the planning processes of selecting and measuring food ingredients. Thus, users will not see redundant changes on the display due to the rearrangement of food ingredients and containers. In the user study of the third prototype, the participants asked if they could turn off the system after they had finished measuring all food ingredients. They explained that they would not be further adjusting the food ingredients and therefore did not need the support of the system. Additionally, unlike the second prototype, the interface did not change after the planning process. Therefore, the cooks may have considered the system unnecessary.

As expected, the system did help the participants plan their meals, which can be seen from the reductions in meal calories or the approach of recommendations in the user studies. However, users chose to ignore feedback and even asked if they could turn off the system once the planning process was finished. There exists a limited time usage of technology during the operation of our system, which could be resulted from the choices we made during the design process. We will discuss it in the following section.

6.3 Technology Limitations and Benefit/Cost Ratios

To explore the relationship between the design choice we made and the limited time usage described above, we use the term defined in the first chapter, the benefit/cost ratio. The benefit refers to the user-perceived value of support from the system, and the cost is the amount of user efforts in operating the system.

In our initial conception, the health-aware kitchen, we envision that cooks would benefit from the system during the entire cooking; meanwhile, they would have to act in compliance within the system limitations. The “inconvenience” or the extra effort for putting up with the system’s limitations is the cost. In the initial conception, the benefit/cost ratio was expected to remain constant as shown in Figure 8, because cooks were expected to receive support continually while they put effort into operating the system.

During the iterative design process, both the problem scope and the design goal were narrowed down from promoting healthy cooking throughout the cooking process (the health-aware kitchen), to raising nutrition and calorie awareness during only meal planning process (the calorie-aware & nutrition-aware kitchens). Restated, the calorie-aware and nutrition-aware kitchens are revised to provide major benefits to the meal planning process. As shown in Figure 9, in a typical meal preparation process, planning actions, such as choosing the type and amounts of food ingredients, are interleaved with cooking actions, such as food processing, mixing, and heating. Since major benefit occurs during the planning process and minor/no benefit during the cooking process, the benefit/cost ratio is no longer static throughout the meal preparation.

During the planning process, the benefit/cost ratio is acceptable to cooks, because they receive the benefit of meal calorie and nutritional feedbacks from the system while using the system. However, the benefit/cost ratio drops during the cooking process, because cooks find little change/benefit in the meal calorie and nutritional information while performing cooking actions. Hence, we observed cooks often ignored the system. However, cooks still have to act in compliance with the system's limitations in order to continue using the system for their next stage of planning. Restated, the cost is the same between planning and cooking processes. The low-benefit/constant-cost explains why cooks asked to turn off the system during the cooking process. This constant cost is due to the system tightly integrated with the kitchen. This fixed design of the system made it difficult for cooks to disengage from operating the system and resume the operation later.

Figure 8. Benefit/cost ratio of health-aware cooking.

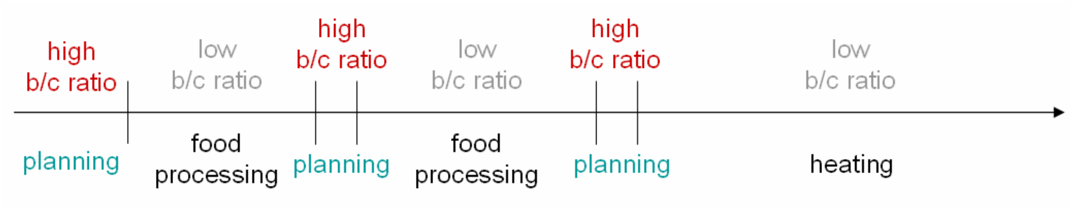

Figure 9. Benefit/cost ratios of calorie-aware cooking.

6.4 Planning

The smart kitchen was intended to support key aspects of healthy cooking such as selecting and measuring food ingredients. Because planning is also an ongoing generative thinking process during cooking activity, observing and differentiating planning activities from cooking is often difficult.

One participant mentioned that she usually starts cooking without a specific dish in mind but that everything becomes clear during the process of cooking. For her, an initial, fuzzy idea may come from a recipe, preferences or food ingredients, which guide her in planning the meal. During the planning process, decisions were made gradually over time to turn the initial fuzzy idea into a meal. Cooks often perform planning and cooking tasks simultaneously to save time, particularly when preparing multiple courses.

This user study revealed similar observations. For example, participants often took many possible food ingredients from the refrigerator and placed them on the counter even though they did not intend to use all of them. This showed that decisions were continuously refined and adjusted during the cooking process. For example, when the participants were cooking one of the courses in the meal, they were still considering what food ingredients to add in order to improve the dish or how the next dish complemented the pervious dish.

The smart kitchen did not adequately support this generative thinking process. As described previously, the smart kitchen indirectly caused cooks to perform these planning activities before starting to prepare a meal. In practice, however, cooks often make decision throughout the cooking process, which is opposite to the original idea of encouraging healthy cooking without affecting original cooking habits. Additionally, the amounts of some ingredients, such as oil, cannot be determined until they are about to be used.

However, planning cooking in advance may be necessary for producing healthy meals using smart kitchen technology. For example, one participant in a user study of the second prototype prepared a meal without advance planning. The resulting meal had more calories than expected, and the recommendation would have been exceeded if there were no further courses to prepare. This example indicates that planning is essential for preparing healthy meals.

Chapter 7

Design Implications

This chapter describes design implications of our UbiComp kitchen system by generalizing the lessons learned from of our experience in designing and deploying an UbiComp kitchen system. We believe that these design implications can be applied to computing systems, embedded in an everyday home environment such as the kitchen, that target supporting and persuading human behaviors. As discussed previously, the use of technology and its limitations in our kitchen have dynamic (unfixed) benefit/cost ratios across different cooking stages. As a result, during phases when the benefit/cost ratios are low, users were inclined not to use the kitchen. Our design implications discuss the lower benefit/cost ratio and try to come up with solutions to address with this issue.

7.1 Leverage Technology Strength

Almost all new technologies have limitations in some aspects. This applies to activity recognition, in which reaching perfect recognition accuracy on complex human activities in the real world is extremely difficult, if not impossible. In order to avoid these recognition errors, systems often place limitations or restrictions on human activities. In our smart kitchen, examples of our limitations include speed of cooking actions, concurrent movements of multiple containers, etc. These activity limitations or restrictions add to the "cost" of inconvenience to users, thus decreases the benefit/cost ratio of using the system. To address this issue, robust technologies that leverage technology strength should be used to reduce the cost of inconvenience to users.

7.2 Modest Human Involvement to Correct System Errors

To support human activities, the computer system attempted to anticipate human intent through activity inference, which if successful, would greatly benefit users. However, as noted earlier, many such systems are imperfect, and small inference errors may produce unacceptable results, which would cause users to distrust the system or even to refuse to use it. This study showed that allowing users to make corrections for the system when recognition errors occurred improved the credibility of an imperfect system. Although manual error correction could be laborious, users would still prefer it to a flawed system with incorrect activity inference [9]. Although introducing human involvement also brings extra cost to users, it is still acceptable.

7.3 Fit User Expectations

User expectations reflect the anticipated benefits of using a system, which vary from one person to another person. User expectations are also influenced by user expertise in the target activity. For example, inexperienced cooks may anticipate that the system could guide them in healthy cooking by providing clear step-by-step instructions because they would be confused by high level guidelines. Clear instructions are much easier to follow and less confusing. However, experienced cooks may prefer high level guidelines but ultimately use their own judgments in the cooking process. Experienced cooks not only have their own cooking styles but also have the experience to evaluate, accept or reject the cooking guidelines. When designing a system, technologies should try to meet different user needs. Clearly understanding user expectations can help realize the benefit/cost ratios of different users, which can be used to design hardware technologies and software solutions needed for a feasible system and avoid the use of overly complex technology for performing simple tasks.

7.4 Summary

The design implications listed above are intended to optimize the benefit/cost ratios when designing a system, which can be achieved only when the expected benefit to the user exceeds the cost of operating the system. Restated, the benefit/cost ratios should be high when operating a system, otherwise, users would simply refuse to use it or turn to other systems. To achieve the balance resulted from different user expectations and applications, the target users and activities should be surveyed in detail, and the system should be designed in accordance with the results.

To use our case for illustration, healthy cooking can support cooks with distinctly different requirements. First, experienced family cooks are not inclined to change their cooking styles but are interested in healthy cooking. The user studies revealed that using oil is critical in calorie control because oils are energy-dense ingredients. A possible solution is an aware bottle that tracks daily usage of oil contained within the bottle so that cooks can monitor oil usage directly on the bottle. The bottle can also be designed to indicate varying amounts of oil being poured from the bottle. This enhanced bottle could be easily built using simple technologies that would be robust in everyday use. Additionally, such aware bottles could be more easily understood by users in comparison to systems with complicated activity inference technologies such as our smart kitchen. We expect that such simple technology might work more effectively than complicated technology. Also, Wei et al. found that a familiar design is crucial for persuading users to behave in unfamiliar ways [31]. Applied in our case, in order to encourage experienced cooks to cook more healthily through adopting new technologies, technologies should avoid conflicting with personal or habitual practices. Familiar designs with limited support are most likely to be accepted.

The second idea targets inexperienced cooks interested in learning healthy cooking. The kitchen could be enhanced with a tutoring system that provided step-by-step instruction for making healthy meals. At each step, the kitchen could ask the cooks to perform certain cooking actions required by a recipe such as “add 10ml of oil” or “simmer over low heat for 3 minutes”. The kitchen could be embedded with sensors such as weighing sensors or temperature sensors to help cooks perform the required cooking actions while checking the correctness of their performance. Although such system would limit cooking activities, i.e., users would be required to follow the instructions without alteration, inexperienced cooks and those highly motivated to learn healthy cooking might be willing to conform to instructions as they perceive a substantial benefit in using the system this way.

Chapter 8

Related Work

The related work is organized into these three categories: smart kitchen, human activity recognition, and persuasive technology for behavioral modifications.

8.1 Kitchen

The CounterActive developed by Ju *et al.* [15] is an interactive kitchen cookbook that teaches cooking by projecting recipes and instructional videos onto kitchen counters. The system is integrated into the kitchen to enable user interaction with the system through the kitchen counter when cooking rather than through a computer.

The Counter Intelligence project from MIT [3] augmented a kitchen with the information projected onto different kitchen objects and surfaces, including the refrigerator, range, cabinet, faucet and drawers. The projected information in these areas supported different tasks related to that area. For example, the faucet had an LED light indicating water temperature. The projected information was designed to provide recipes and help users in multitasking during meal preparation.

The Cooking Navi developed by Hamada *et al.* [13] is a cooking navigation system that helps users prepare multiple dishes simultaneously through appropriate instructions generated from optimized scheduling of recipes. The instructions are presented with multimedia information including text, video and audio to facilitate communication to users.

Siio *et al*. [26] designed the Kitchen of the Future to enhance communication and learning related to food preparation. The kitchen was augmented with LCD displays as well as cameras and microphones for recording cooking processes. Three applications, including recording and replaying of a cooking process, videoconferencing for cooking instructions, and interactive cooking navigation were implemented to provide assistance in different aspects of food preparation.

Instead of providing instructional support based on recipes or cook books, the Cook's Collage created by Tran *et al*. [28] focused on assistive multitasking during food preparation. The digital assistance comes in the form of a memory aid system that recognizes and displays a summary of ongoing and recently completed cooking actions to help family cooks remember and resume from an interruption such as answering a phone call. The system proved helpful for performing tasks requiring repetitive action.

Projects described above targeted efficiency improvement in meal preparation by using computing systems to instruct and guide cooks. In comparison, our smart kitchen was designed to avoid instructing family cooks what they should do because most of them have their own cooking style. Instead, our kitchen was designed to provide health awareness to family cooks as a means to encourage healthy cooking.

8.2 Recognition

The Intelligent Kitchen project [22] presented an activity recognition system that adopted data mining techniques to predict the next cooking action and offer suggestions through an LCD display or a robot.

Kranz *et al*. [17] developed an augmented cutting board and knife that inferred food ingredients being prepared from a combination of weight readings of load cells underneath the kitchen counter and a force/torque transducer embedded in the cutting board and knife. The system demonstrated the possibility of integrating sensors into daily objects for detecting activity contextually without affecting their usability.

The VeggieVision created by Bolle *et al*. [2] is a product identification system based on computer vision. To perform recognition, the system first extracted various features of a grocery item, such as its color, texture and shape, and then compared these features to a-priori trained database containing feature signatures of grocery items.

Chang *et al*. [7] developed the Diet-aware Dining Table to track what and how much users consumed on the dining table. The system applied a weight transfer algorithm to track the transfers of food ingredients among various tabletop containers, as well as disappearance of food ingredients from personal containers into each table participants. These eating and transfer actions were inferred by weight readings of load cells underneath the dining table.

Mankoff *et al*. [21] created a system that analyzed shopping receipts to track the purchase and consumption of household food items. Based on the tracked data, the system generated suggestion to users on how to purchase healthier food items or to correct malnutrition caused by a specific diet pattern.

8.3 Persuasive Technology

The Playful Tray created by Lo *et al*. [20] is an enhanced food tray with a digital game to address long mealtime problem of children. The tray uses the eating action of the child as input to a racing game. The child can select a favorite character to race in the game at the start. A randomly selected character moves one step forward as the system detects eating action. To win the game, the child must eat at an appropriate speed.

Playful Toothbrush developed by Chang *et al*. [8] has a similar concept as the Playful Tray. It motivates young children to learn proper brushing skills by introducing a tooth brushing game which accepts input based on the tooth brushing actions of the user. Both the Playful Tray and Playful Toothbrush are designed to provide an incentive to engage in the target activities.

To encourage physical activity, the UbiFit Garden [9] uses on-body sensors to infer the actions of users, which are represented in a virtual garden shown on a mobile phone display. To maintain the virtual garden, users are encouraged to perform physical activities.

Lin *et al*. addressed a similar problem by introducing Fish'n'Steps [19], a social computing game that promotes physical activity by linking the daily foot step count of the user to the growth of a virtual fish. In addition to displaying a virtual fish for each player, fishes belonging to other players are shown on the display to create a competitive game. Thus, users are encouraged to perform the target activity by competition with other players rather than by self-motivation.

In comparison to the work described above, our smart kitchen adopted different means to promote healthy cooking behaviors. Instead of bringing enjoyment or using social pressure, our smart kitchen was building self-efficacy of family cooks in perform healthy cooking by using digital technologies to simplify the task of performing healthy cooking, thus motivate them to change their cooking behavior.

Chapter 9

Conclusion

This thesis proposed a health-aware kitchen to encourage healthy cooking and help family cooks overcome the difficulties of healthy cooking. The kitchen was augmented with sensors to automatically track cooking activities, and provided real-time nutritional feedback to family cooks. In the iterative design process, three prototype interfaces were created, and user studies were conducted to evaluate their effectiveness. Results of user study on the first prototype suggested effectiveness for raising awareness of nutritional properties. Results of user study on the second prototype showed the participants were able to meet or approximate the caloric recommendations of the system. Furthermore, user study results suggested that encouraging healthy cooking by providing health-related information during the cooking process is feasible. However, further improvement is needed for practical use.

Three main findings from our user studies were discussed: (1) participants tended to ignore the system in later stages of cooking; (2) after performing meal planning, participants asked if they could turn off the system because they no longer needed the information; (3) the performance of participants differed when using the system. These findings suggested that some users were unwilling to use the smart kitchen, and other differences in expectations of the kitchen were noted. After reviewing the initial concept, proposed solution, iterative design process and user studies together with the three findings, the potential problems of the smart kitchen were clarified and which were mainly resulted from an inappropriate use of technology during the design process.

Several design implications were identified that can be generalized for future research in applying UbiComp technology to support persuasive systems in everyday environments such as a kitchen. (1) Smart technology can complement user activity in order to increase the benefit/cost ratios of a system. (2) Introduce modest human involvement in designing the system is acceptable if it is in accordance with user expectations.

Appendix A

Publications of Jen-hao Chen

Below is a list of publications that I have achieved in the study of master program:

1 Pei-Yu Peggy Chi, Jen-Hao Chen, Hao-Hua Chu, Jin-Ling Lo, **"Enabling calorie-aware cooking in a smart kitchen"**, in Proceedings of the Third international Conference on Persuasive Technology (Persuasive 2008), Oulu, Finland, June, 2008.

2 Jin-Ling Lo, Tung-Yun Lin, Hao-Hua Chu, Hsi-Chin Chou, Jen-Hao Chen, Jane Yung-Jen Hsu, Polly Huang, **"Playful tray: adopting UbiComp and persuasive techniques into play-based occupational therapy for reducing poor eating behavior in young children"**, In Proceedings of the 9th International Conference on Ubiquitous Computing (UBICOMP 2007), Innsbruck, Austria, September 2007, pp 38-55.

3 Pei-Yu Chi, Jen-Hao Chen, Shih-Yen Liu, Hao-Hua Chu, **"Designing smart living objects - enhancing vs. distracting traditional human-object interaction"**, in Proceeding of the 12th International Conference on Human-Computer Interaction (HCII 2007), July 2007, pp 788-797.

4 Pei-Yu Chi, Jen-Hao Chen, Hao-Hua Chu, Bing-Yu Chen, **"Enabling nutrition-aware cooking in a smart kitchen"**, in ACM CHI 2007 Extended Abstract (Work-in-progress) , April 2007, pp 2333-2338.

5 Jen-hao Chen, Keng-hao Chang, Pei-yu Chi, Hao-hua Chu. **"A smart kitchen to promote healthy cooking"**, in Poster Session & Adjunct Proceedings of the 8th ACM International Conference on Ubiquitous Computing (UBICOMP 2006), California, September 2006.

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