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Master thesis

幫助使用者健康烹飪的卡路里感測智慧型廚房

Enabling Calorie-Aware Cooking in a Smart Kitchen

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Abstract

As a daily activity, home cooking is an act of care for family members. Most family cooks are willing to learn healthy cooking. However, learning healthy cooking knowledge and putting the learned knowledge into real cooking practice are often difficult, due to non-trivial nutritional calculation of multiple food ingredients in a cooked meal. This work presents a smart kitchen with UbiComp technology to improve home cooking by providing calorie awareness of food ingredients used in prepared meals during the cooking process. Our kitchen is embedded with a calorie tracker that can track the number of calories in the used food ingredients. The calorie tracker is developed based on a hybrid sensing method that integrates weight sensing from load cells and image processing from cameras. Thus, the system can provide real-time calorie feedback to users through an awareness display. In this thesis, we have designed and implemented three applications of this smart kitchen, in which each of these three applications targets a different goal in raising user awareness on (1) nutrition facts, (2) used calories, and (3) used calories in consideration of nutritional balance. For evaluation, separate user studies were conducted on each of these applications. Our user study results suggested that providing real-time calorie awareness can be an effective means in helping family cooks maintain a healthy level of calories in their prepared meals.

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Chapter 1

Introduction

1.1 Motivation

After a busy day, many people find nothing better than a delicious home-cooked meal prepared by a caring family member. This is in accordance with a recent study indicating that most people still favor home-cooked meals or cooking meals from scratch [10]; in Europe, 52% and the US, 44% of people prefer scratch cooking.

For many family cooks, preparing a tasty meal is as important as a healthy meal with the appropriate amount of calories. However, average family cooks may not know how many calories are in their cooked meals after raw food ingredients are mixed and cooked, or whether these meals are considered healthy and offer a good number of calories for their family members [20]. There are several reasons for the difficulties in preparing a healthy meal at home. First, the knowledge for healthy cooking may not be easily learned for average family cooks, especially the relationships between food ingredients and calories. Second, even though family cooks have learned the healthy cooking knowledge, it is difficult to put the learned knowledge into real cooking practice. For example, when cooking from scratch, they cannot easily follow the steps of calculating calories during an intense cooking activity: first they have to estimate accurately the amount (weight) of each food ingredient used (such as oil, meat, vegetables and others), and then look up a food calorie table to calculate and sum up the overall number of calories used in a course or a meal [35]. Therefore, they are reluctant to put in much effort on examining and changing their everyday cooking styles. This may also respond to the results of a study on the food portion sizes inside the home: the portion sizes and energy intake of foods prepared or consumed at home had increased largely in the past years (during the period 1977-1998 [37]).

This lack of knowledge and practice of healthy cooking may lead to calorie over-consumption or nutritional imbalance at home, thus substantially increase the risk of obesity and diet-related chronic diseases in family members in the long run [50]. Therefore, a method for assisting family cooks to be more aware of preparing healthy meals in home kitchens is in demand.

1.2 Problem and Proposed Solution

The objective of this thesis is to assist family cooks in preparing healthy meals during their cooking process. The approach is to apply digital technologies to a home kitchen, to greatly simplify the learning and practice process of healthy cooking. By making the healthy cooking process easy to perform, our smart kitchen motivates family cooks to change and adapt to healthy cooking behaviors. Our approach is based on the general “reduction technique” proposed by Fogg [12] to simplify the complex healthy cooking behavior into an easy-to-perform activity. Additionally, our approach finds support in a human psychology study of self-efficacy by Bandura *et al.* [2], in which self-efficacy is defined as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives". When applied to healthy cooking, if the expected efforts exceed people's beliefs about their expected performance, users may regard they are lack of skills and self-efficacy to perform healthy cooking behaviors. Based on the self-efficacy theory, *increasing accessibility* of calorie information to family cooks simplifies healthy cooking process, thus raises their confidence and willingness on performing healthy cooking. By bringing awareness of calories in food ingredients to family cooks, our smart kitchen aims to persuade them to cook within a proper calorie level.

To achieve this goal, we adopt the ubiquitous computing (UbiComp) approach, in which digital technologies are seamlessly embedded into the physical kitchen environment to help family cooks with healthy cooking during their cooking process. One central theme in UbiComp, as put forward by Weiser [49], is to bring digital technologies outside the virtual digital world and into our physical everyday environments, such that they can improve our experience of living in the physical world. By embedding ubiquitous sensing and computing into our everyday living objects and environments, we can provide personalized, just-in-time, contextual knowledge relevant to our everyday lifestyle. Therefore, we believe that through sensing human physical cooking behaviors, calorie awareness and intelligent interaction can be designed to influence, shape, and persuade users into certain healthy cooking behaviors.

This thesis presents a Calorie-aware Kitchen that provides family cooks with awareness on the number of calories in their home cooked meals, thus enhances family cooks' willingness to make healthy meals with the appropriate amount of calories, as recommended by nutritionists. The Calorie-aware Kitchen is augmented with sensors that track the food ingredients used during cooking, and provides real-time digital feedback to raise healthy cooking awareness. When a user prepares a meal, the kitchen presents calorie information whenever the user performs a cooking action that changes the amount of food ingredients on the kitchen counter or the stove, such as by adding meat, pouring oil, etc. Given the number of calories of each ingredient, an average family cook can perceive calorie information in the amounts of ingredients or the composition of a course. The developed kitchen also suggests the recommended number of calories for a meal, which is based on the Harris-Benedict equation [18], for the purpose of comparison to the number of calories in their current cooked meals.

1.3 Design Challenges and Contribution

This thesis confronts several design challenges over cooking, nutrition, technology, and balance with human perception. It contributes in the following aspects. First, in order to bring real-time feedbacks, sensing cooking activity itself is challenging. Cooking is a complex daily activity that happens in almost every home environment. Since it has been lasting for a long time, cooking behavior is various from people to people, based on personal preferences or family styles. We observed and analyzed common cooking behaviors, and generalized a solution that can apply to average family cooks to use. Thus, this system can sense ingredients used, i.e. calorie changes when preparing and cooking ingredients.

Second, this work can be seen as a platform of creating calorie-related applications of cooking process in the kitchen. The Calorie-aware Kitchen senses calorie changes and thus generates calorie-change events (i.e., names and positions of ingredients, and their contained calories), for different applications to visualize the information. In this thesis, we present different designs to assist family cooks with awareness of nutrition facts, of calorie, and calorie-control. The kitchen may also apply for more purposes such as teaching cooking steps, cooking commonsense, etc.

Third, showing adequate feedbacks in the right timing is not as easy task, especially in the busy cooking scenario. By conducting three user studies, we are convinced that our design to bring real-time calorie feedbacks in the cooking process is effective to family cooks to learn healthy cooking and make adjustments.

1.4 Thesis Organization

The rest of this thesis is organized as follows: Chapter 2 introduces our contextual inquiry of home kitchens in which user requirements of the Calorie-aware Kitchen were gathered. Chapter 3 describes our prototype design and details of implementation that how the kitchen tracks calories by detecting ingredients during cooking. Then, Chapter 4 presents three applications on how the kitchen can increase users' awareness through revealing calorie information, along with user studies of how the system may help family cooks to be aware of calories and control them by adjusting the amounts of ingredients. Chapter 5 summarizes lessons learned through these applications. Chapter 6 discusses related work. Conclusions are finally drawn, with recommendations for future research in Chapter 7.

Chapter 2

User Requirements

Prior to designing our Calorie-aware Kitchen, we gathered user requirements by first observing and understanding how users cooked in home kitchens. We have conducted a contextual inquiry, in which the results are used to obtain user needs and design considerations. Additionally, we surveyed users' current methods of calculating meal calorie in home kitchens to understand the difficulties of cooking within a proper calorie level. Finally, we have performed a task analysis on their cooking activities, in which the results are used to understand complexity of cooking activities in the kitchen and provided additional design considerations when applying sensing technology and digital feedbacks to family cooks.

2.1 Contextual Inquiry in a Home Kitchen

This work targets experienced family cooks who are willing to cook more healthily but are reluctant to put in much effort on learning and calculating calories. An experienced family cook is defined as someone who can cook without following any recipes or relying on weight scales to measure food ingredients.

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 a regular dinner for their family. During the cooking process, they were observed and videotaped; questions asked about their meal preparation and understanding to nutrition and calorie needs.

Our findings are as follows. (1) They expressed the desire to cook healthily, especially with respect to calorie and nutritional balance. However, given busy schedules, they could not afford too much time or make much effort to learn and follow the complicated steps of weighing food ingredients and calculating nutritional values during actual cooking. They preferred simple-to-understand, practical guidelines for them to refer. (2) Family cooks commonly added ingredients based on experience or preference (oil, butter, meats, for example). Three of them stated that they were unsure about whether their own cooking styles were healthy. (3) Since cooking is an activity that requires ongoing planning and thinking about the next cooking step, family cooks would like to focus solely on cooking. They do not like distractions from unrelated activities, such as operating complex electronic interfaces on refrigerators or microwaves, because distractions are likely to cause cooking errors. They suggested that they want only simple, highly relevant information on cooking itself. (4) They regard a kitchen as part of a home and not a place of work. No standard procedure should instruct them how to operate various tools in a kitchen to produce meals.

The contextual inquiry led to the following design considerations in designing the Calorie-aware Kitchen: (1) the kitchen should offer real-time calorie information on food ingredients during their regular cooking process, reduce the effort required to calculate calorie manually, and help family cooks easily perceive calorie information. (2) Calorie recommendations should be provided for ease of comparison and adjustment. (3) Information should be presented simply, so that family cooks can easily grasp the calorie information by taking quick glances. (4) Information should help family cooks make their own decisions, without constraining his or her natural cooking habits. When cooks must concentrate, they can choose to ignore the informational display.

2.2 Cooking within a Proper Calorie Level

Studies have shown that calorie count can be derived from weights of food ingredients [35], and the calorie count is additive when composing various food ingredients. For average family cooks to calculate the meal calorie count, they take the following steps. (1) They need to measure the weight of each food ingredient that go into a meal during a planning phase. Food ingredients include the main ingredients (such as meat, fish, and vegetables), medium and dressing (such as oil, cream, sauce, and soybean oil). (2) They look up a food calorie table to find the unit calorie of each ingredient per 100 grams. For example, the calorie of 100 grams of beef is 390 kcal. (3) The calorie of each ingredient is calculated using the ratio of weights. For example, the calorie in 140 grams of beef is 390*(140/100) = 546 kcal. (4) After measuring all the raw ingredients (usually more than 10 kinds in an average meal), family cooks sum up the calories of multiple ingredients to determine the calorie count in the meal. (5) Finally, they adjust the amounts of ingredients when the meal calorie count is over the recommended calorie count for their target family size. Since this calorie counting and budgeting process involves multiple non-trivial, time-consuming steps, it becomes difficult for average family cooks to put this healthy cooking process into everyday practice. Although the use of a commercial calorie scale [11] alleviates some user effort in the calorie ratio calculation, the additional efforts of weighting each food ingredient by a scale and then tracking and summing up the overall calorie count are still formidable for average family cooks.

To address the difficulty of calorie counting, USDA (United States Department of Agriculture) proposed dietary guidelines for measuring ingredients [45]. In these guidelines, food ingredients are classified into five groups: meat and beans, oils, vegetables, grains, and fruits. Rather than using weight, which is difficult for a human to assess quantitatively, a concept of "serving" is used as a measurement unit to approximate a certain quantity of food ingredients and its recommended level. A serving size is approximated by comparing to the size of a human fist or some common objects (Fig. 1). However, this method is not popular to average family cooks because its size measurement system is not simple enough as different food groups use different measurements.

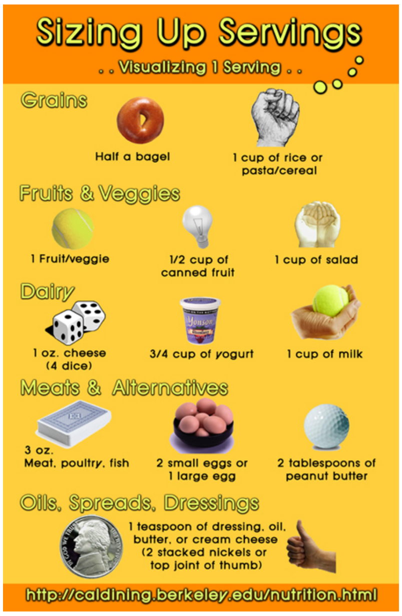


Fig. 1. Sizing up food ingredients to servings by comparing to a human fist or common objects [7]

During the cooking process, we observed two additional problems in measuring and counting calorie of each ingredient in advance during the planning stage. First, certain ingredients such as oil or cream are often added directly from the bottles to a pan during the cooking stage, thus, it is not practical to measure their weights other than the cooking context during the planning stage. Since oil and cream are added based on the experience of the family cooks, they may under-estimate or over-estimate the amounts to use. Second, at the start of the planning stage, family cooks often miss preparing some parts of the food ingredients, in which they then prepare later during the heating stage. For example, we observed that some family cooks forgot to measure soy sauce or cheese that they would later add to flavor a dish. However, some of these ingredients contain high calorie that significantly increase the calorie count.

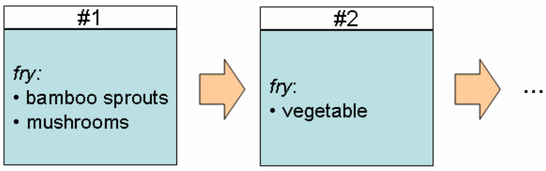
Based on our above findings in the existing methods of calculating meal calorie at home cooking we have identified many opportunities where digital technology can be used in a home kitchen to reduce the difficulties in calculating meal calorie for average family cooks.

2.3 Task Analysis of Cooking Activity

To design technology that can sense calorie-change in the cooking context at home, we first analyze home cooking activity, i.e. how experienced family cooks manipulate and operate objects (e.g. ingredients, containers, and utensils) in the kitchen. Our analysis is based on (1) on-site observation in home kitchens while the experienced cooks were cooking usual meals with *several courses* for their families, and (2) recorded videos of these cooking sessions under the consent of these family cooks, and (3) answers to our questions when these family cooks performed certain actions that were of interested for further inquires (i.e., finding out the reasons behind these actions).

We present our findings based on a rough time-ordered sequence of actions while cooking in a kitchen. Upon entering the kitchen, (1) family cooks first observed what ingredients they had in refrigerator or cabinets, and then planned for meal courses based on these ingredients. Some of them indicated that sometimes they started to think about what to cook before going to the kitchen for cooking. For example, they might start planning when they were shopping for foods in the food market or doing housework. (2) They planned the sequence of cooking multiple courses by considering several factors, e.g. the time they needed to prepare and cook each course, the complexity of preparing, and how long the course could stand after cooking (for example, it was better to enjoy fried foods immediately after cooking, which should be prepared the last). (3) When they started the first course, they took out the required food ingredients, such as vegetables and meat, for preparation (to wash, cut, drench, etc.). Often they *placed the prepared ingredients in containers*, such as a plate, bowl, basket, and cutting board. Then, they *adjusted* the amounts of ingredients, followed by food processing such as cutting, cleaning, washing, shucking, etc. During this phase, they *mainly worked on the kitchen counter* and interspersed with frequent visits to a refrigerator and cabinets to take ingredients or utensils. They also used water from a tap and sometimes worked food ingredients in the sink directly. (4) After placing prepared foods on the counter, they began to cook. In most cases, they used high temperature to heat the ingredients, such as (frequent) frying on the stove, or (less frequent) heating with oven or microwave. Sometimes they just mixed and stirred ingredients together (e.g. salad). During this period, they mainly mixed all the ingredients together while adding additional elements such as oil, salt, butter, and soybean oil, to flavor the food mixtures. At the same time, if no cooking action such as stirring the food mixtures is needed, they might start preparing other ingredients (go to step 3) for the next course. (5) When the foods were cooked, they stopped heating (e.g. turning off the fire on the stove, the power of oven and microwave), followed by placing cooked foods into a container, e.g. a plate or a bowl. Then, they moved the completed food dish to a safe and far-away place such as on a dining table. This action freed up counter spaces and allowed them to focus on cooking other courses. An example of the above sequence is shown in Fig. 2.

(1) *observe* available ingredients
in the kitchen and make a meal *plan*



(2) *decide* the sequence
of cooking several courses

(3) *adjust* and prepare food ingredient
on the counter

(3) *adjust* and prepare ingredient
in the sink

(4) *put and adjust* the raw ingredient (oil) into a Chinese pan on the stove

(4) *put* the prepared ingredient into the pan

(4) *cook* (fry) the foods on the stove

(3) *adjust* and prepare ingredients for the next course while heating

(5) *finish* one course and put foods in a container

(3) *adjust* and prepare ingredients for the next course

(4) *put* the prepared ingredients into the pan

Fig. 2. An example sequence (step 1 to 5) of cooking multiple courses in a home kitchen.

Our observed family cooks iterated steps 3 to 5 until they finished all the courses (Fig. 2). Note that these steps might overlap with each other, especially step 3 (preparing foods) and step 4 (cooking foods), as shown in Fig. 3. At the end of meal preparation, they performed some simple and quick kitchen cleanup (e.g. turning off the smoke-removal apparatus and fans, washing some utensils, and putting things back to their original place) and left the kitchen.

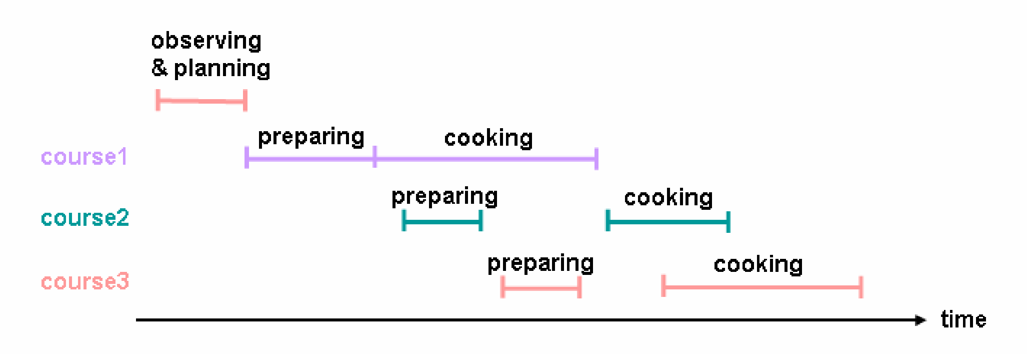


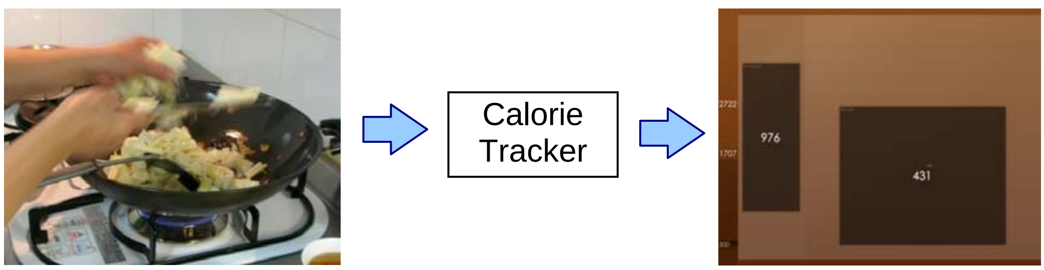
Fig. 3. An example timeline of cooking multiple courses for a dinner

The above task analysis gives some insights into complex cooking activities in a kitchen. These insights help derive our design considerations when applying sensing technology and digital feedbacks to these family cooks.

Chapter 3

System Design and Implementation

Based on the above findings and design consideration, we designed a kitchen by sensing whenever a family cook does an action that may result in a calorie change of the meal during the cooking process (Fig. 4 (1)), our system tracks the amount of calorie changes and shows the calorie change as feedbacks in real-time (Fig. 4 (2)). Thus, the family cook can perceive information immediately and learn how much calorie is in the food ingredient associated with his/her most recent action (Fig. 4 (3)).



(1) The family cook performs a cooking action

(2) Our system tracks the calorie change

(3) The family cook gets calorie awareness mapping to the action

Fig. 4. An example flow of how users can interact with the system

An initial prototype of our augmented kitchen is shown in Fig. 5(a). The initial kitchen was a standard IKEA[1] kitchen. Our digital extension comes in the following two modules: (1) A calorie tracker that tracks the calorie, composition, and position of food ingredients currently on the kitchen counter or stove; and (2) an awareness display that provides real-time information on food ingredients associated with the current cooking action. Our kitchen does not assume any cooking plan from users prior to using this system, i.e., there is no need for users to input any cooking plan to our system in advanced.

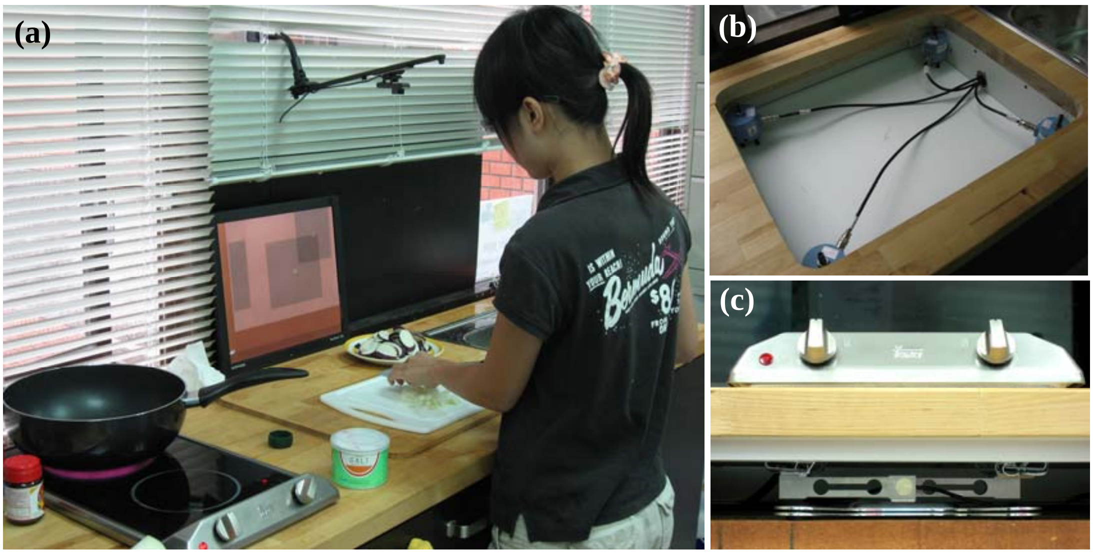


Fig. 5. (a) Calorie-aware Kitchen with digital feedbacks of calorie information during cooking process. An overhead camera is deployed over the counter. Weighing sensors are deployed under counter (b) and stove (c).

In the following subsections, we introduce the design of our calorie tracker in details.

[1] IKEA Group, http://www.ikea.com/ (2008)

3.1 Calorie Tracker Design

To track calories used during a cooking process, whenever a user performs a cooking action (adding or removing ingredients to or from a container) that may change the number of calories, the system must detect this 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. As shown in section 2.2, to calculate calories, the weight and the composition of food ingredients in dishes need to be determined. Thus, we designed a calorie tracker that employed a hybrid sensing solution by combining weighing and camera sensing for accurate detection. Fig. 6 depicts the architecture for cooking activity recognition based on hybrid sensing.

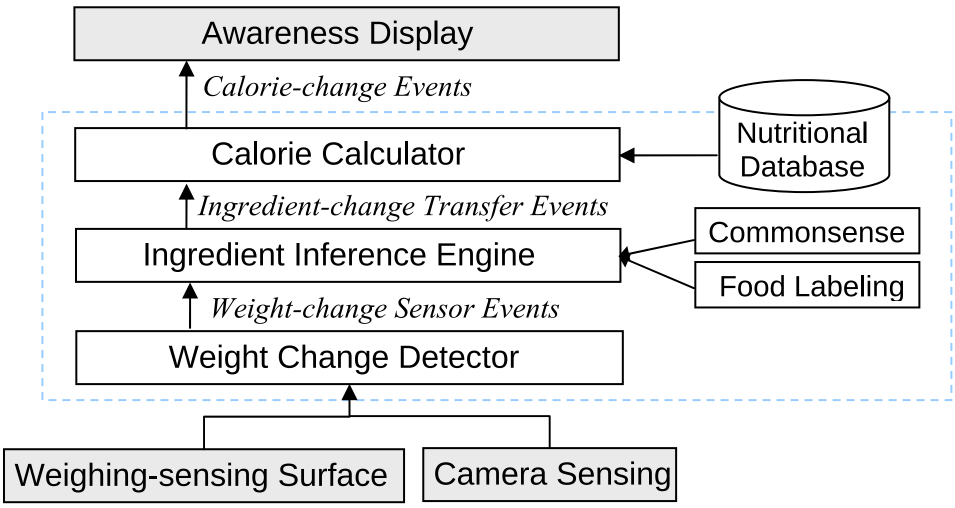


Fig. 6. Calorie tracker architecture

3.2 Weighing-sensing Surface

To calculate calorie in food ingredients, we deployed a weighing-sensing surface in the kitchen. Based on our observations of cooking activities described in Section 2.3, 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 weights of ingredients that are added to each container to calculate their calories. The prototype design was based on the load sensing table [38] in which four weighing sensors were installed at the four corners underneath the kitchen counter with an area of 55x44 cm^2 (see Fig. 5(b)). In order to ease human labeling of every weight-changing event, 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 and ingredients 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 (Fig. 5(c)). All of the weighing sensors are attached to weight indicators with a resolution of 1 gram, which output readings through a serial port at a frequency of 8 samples per second.

3.3 Camera Sensing

Camera sensing using video analysis is employed to improve the accuracy of detecting food ingredients by filtering noises from the weighing-sensing surface. Based on our preliminary experiments, detection using only weighing sensors was inaccurate with a high recall rate of 54%, or 46 detections of noise per 100 weight changes. Detection errors frequently occurred during cooking actions that generate lots of weight noises on the kitchen surface, such as cutting or stirring ingredients with hands and/or utensils, though the intention of these actions is not to change the amount of foods. Meanwhile, we observed that the changes in video domain of such cooking actions are insignificant. For example, in the process of cutting chicken into slices, the family cook uses one hand to hold the chicken while the other hand to slice it with a knife, until finishing cutting the whole piece of chicken. Therefore, video analysis using a color histogram comparison is performed to filter false detections from weighing sensors. We deployed an overhead camera over the kitchen counter to capture an overhead image of the counter (Fig. 5(a)). Our algorithms are described in the following subsection.

3.3.1 Weight-change Detection Algorithm

To filter weight noises produced by cooking actions, the concept of video segmentation and shot boundary detection is applied to our system. To segment a video with different shots, which is defined as a continuous sequence of frames provided by one camera, various image processing methods can be used. Examples are to compare the differences of pixels, histograms, and features such as edges and motions, between frames of a video. Frames with similar attributes can be seen as in the same shot, which in our cooking scenario, remains in the same cooking actions with no actual weight changes. Therefore, in our Weight-change Detection algorithm, we compare frames (images) taken at the times before and after the occurrence of the weight change by analyzing their color histograms. Histogram comparison is insensitive to object movements [22][5], thus it can filter out weight noises because images with similar cooking actions and objects (such as keeping cutting or stirring chickens with hands in a plate as Fig. 8(a)(b)) differ only slightly in color histograms. In contrast, a real weight change with ingredient or container differences is more likely to be classified by the algorithm as a weight change due to the large change of color histograms (Fig. 8(c)(d)).

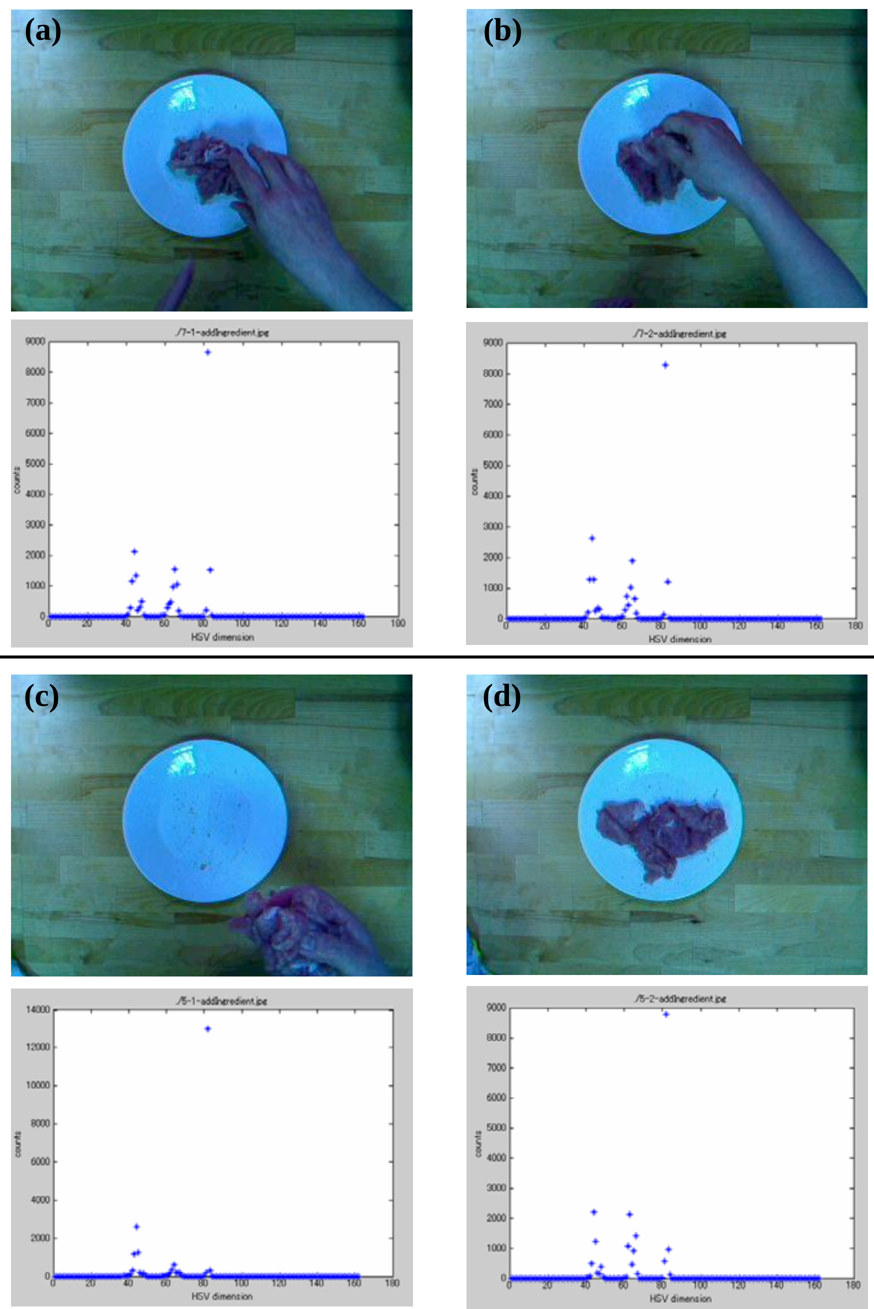


Fig. 7. Color histogram comparison of images. Figures (a) and (b) show that images of similar actions and objects with no ingredient change can be filtered due to their similar histograms, where the x-axis stands for 162 dimensions and the y-axis stands for numbers of pixels. Figure (c) and (d) show that a real weight change can be differentiated by different color histograms.

The Weight-change Detection algorithm works as follows. First, it analyzes color histogram of a frame i as an n-dimensional vector $H_i(j) = 1, \ldots, n$, where n is the number of color segments and $H(j)$ is the number of pixels from the frame i with color range j. The algorithm considers colors in the HSV space which is less sensitive to lights [22]. It divides H (hue) dimension into 18 levels, S (saturate) into 3 levels, and V (value) into 3 levels, with a total 162 bins (n =162) for better discrimination.

After analyzing each image into a 162-dimensional vector, the algorithm sums up the bin-to-bin differences $D(i, i+1)$ between two frames at time t and $t-1$ by the following formula. If the absolute sum $D(i, i+1)$ is greater than a threshold T, the algorithm infers that there is a real weight change on the kitchen surface. Otherwise, it filters this weight change as a noise. Based on our experience, the image difference threshold is set at 30% of the total number of pixels.

$$D(i,i+1) = \sum_{j=1}^{n} \left| H_i(j) - H_{i+1}(j) \right| > \text{threshold } T$$

3.3.2 Camera Filtering Algorithm

Fig. 8 shows our Camera Filtering algorithm. When the weighing sensors under the kitchen counter detect a weight change at a certain position, our system compares the images by the Weight-change Detection algorithm. Based on our assumption that every ingredient must be placed inside or on a container, we define the following sensing conditions to acquire better accuracy: If the kitchen surface does not have any container at the specific kitchen counter position where the weight change occurs, i.e. the real weight change indicates a new container is placed, the **whole image** covering the entire kitchen counter is examined by the

Weight-change Detection algorithm. Then, the Region Growing algorithm is used to identify the pixel region of this container. By doing so, if the weight change occurs on an existing container (such as adding or removing ingredients, cutting or stirring ingredients in a plate), only the histogram of the **container region** in an image is examined by the Weight-change Detection algorithm. This enables the camera sensing to achieve better accuracy by comparing local histograms based on spatial information.

Algorithm camera-filtering (*position, Frame1, Frame2*)

Input: the position (x,y) of weight change on the kitchen surface;

    2 consecutive frames in the video: Frame1 in time t-1, Frame2 in time t.

Output: isWeightChange (Is there a real weight change or not).

begin

    if not *hasContainer(position)* **then**

        weight-change-detection (*Frame1, Frame2*);

        if *isWeightChange* **then**

            region-growing (*Frame1, Frame2*);

    else

        weight-change-detection (region of container in *Frame1, Frame2*);

end

Fig. 8. Camera filtering algorithm using video analysis

3.3.3 Region Growing Algorithm

To identify the region of a container, the Region Growing algorithm using image processing is used. At first, we create the difference image between the two frames by comparing their HSV colors. Since the approximate position of the container can be detected from the weighing sensors (see Section 3.2) underneath the kitchen surface, this position on the kitchen surface can be mapped to the position on the difference image where it is used as the starting point for the Region Growing algorithm. In other words, the algorithm starts from this starting point, performs search for similar neighboring pixels, and grows the container region gradually until it identifies the approximate range [13]. An example of how the Region Growing algorithm works is illustrated in Fig. 9.

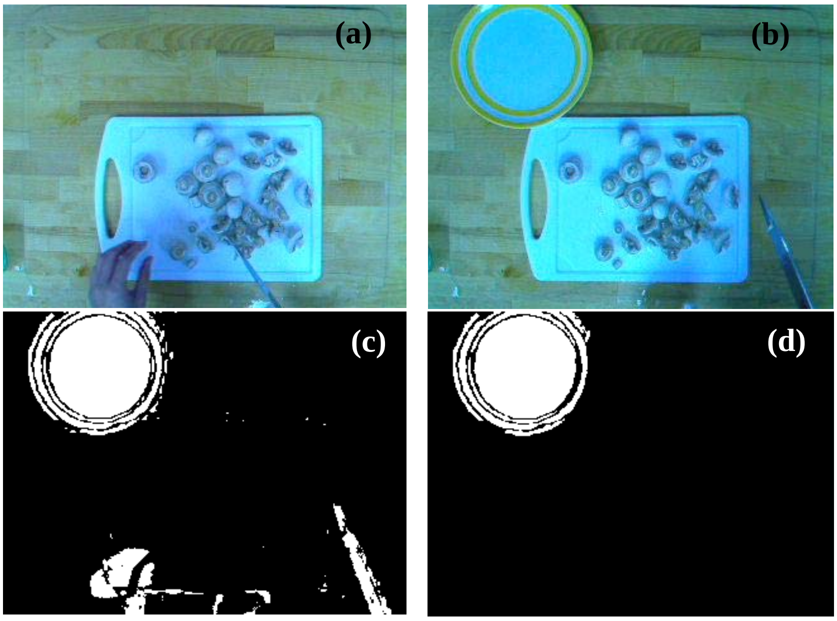


Fig. 9. Sample inputs of previous time moment (a) and current time moment with weight change (b) that a new plate is placed on the left-upper corner; difference image (c) between (a) and (b), and result of Region Growing algorithm (d) that identifies the region of the new plate.

3.4 Cooking Activity Inference

Based on the hybrid sensing method that combines both weighting-sensing surface and camera vision analysis, the calorie tracker uses the cooking activity inference to recognize Calorie-change Events occurred on the kitchen surface. The cooking activity inference is designed as an event-triggered system as shown in

Fig. **6** in section 3.1. Table 1 presents the three types of events from high-level to low-level.

Table 1. Calorie-change, Transfer, and Sensor events

Calorie-change Events
Calorie-Change (container$_i$, Ingredient, Δcalorie), indicates that *Container$_i$* (at a known position) has been added/removed *Ingredient*(s) of *Δcalorie* kilocalorie
Ingredient-change Transfer Events
Ingredient-Change(container$_i$, Ingredient, Δweight), indicates that *Container$_i$* (at a known position) has been added/removed *Ingredient*(s) of *Δweight* grams.
Weight-change Sensor Events
Weight-Change(Δweight, position), indicates a weight change of *Δweight* grams at *position* (x,y) over the kitchen surface.

First, at the lowest level, 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. By processing the *Weight-change* Sensor Events, each ingredient transference is inferred by matching weights with a weight matching algorithm, which is similar to that in our earlier work of eating activity recognition on the Diet-Aware Dining Table [8]. 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 ("container$_1$", "salad oil", 50 grams) is sent to the calorie calculator. However, since cooking activities are far more complex than eating activities, additional transfer inference rules were introduced into the engine and original rules were modified as shown in Table 2. Furthermore, commonsense knowledge on cooking was added to enhance the inference engine. We will introduce in details in the next subsection.

Table 2. Inference rules of Ingredient-change Transfer Events

Weight decrease	$\textit{Weight-Change}(\Delta weight_i, position_i) \cap \Delta weight_i<0$ $\cap\ hasContainer(position_i) \cap hasIngredient(position_i)$ $\rightarrow \textit{Ingredient-Change}(container_i, Ingredient, \Delta weight_i)$
Weight increase with exact weight match	$\textit{Weight-Change}(\Delta weight_i, position_i) \cap \Delta weight_i>0$ $\cap\ hasContainer(position_i)$ $\cap\ \textit{Ingredient-Change}(container_j, Ingredient, \Delta weight_j)$ $\cap\ \Delta weight_j<0$ $\cap\ \lvert\Delta weight_j\rvert - \lvert\Delta weight_i\rvert \leq Threshold$ $\rightarrow \textit{Ingredient-Change}(container_i, Ingredient, \Delta weight_i)$, remove $\textit{Ingredient-Change}(container_j, Ingredient, \Delta weight_j)$
Weight increase with partial weight match	$\textit{Weight-Change}(\Delta weight_i, position_i) \cap \Delta weight_i>0$ $\cap\ hasContainer(position_i)$ $\cap\ \textit{Ingredient-Change}(container_j, Ingredient, \Delta weight_j)$ $\cap\ \Delta weight_j<0$ $\cap\ \lvert\Delta weight_j\rvert - \lvert\Delta weight_i\rvert > Threshold$ $\cap\ \lvert\Delta weight_j\rvert > \lvert\Delta weight_i\rvert$ $\rightarrow \textit{Ingredient-Change}(container_i, Ingredient, \Delta weight_i)$, update $\textit{Ingredient-Change}(container_j, Ingredient, \Delta weight_j+\Delta weight_i)$
Weight increase with no weight match	$\textit{Weight-Change}(\Delta weight_i, position_i) \cap \Delta weight_i>0$ $\cap\ hasContainer(position_i)$ $\rightarrow$ [action: identify the name of *Ingredient*] $\rightarrow \textit{Ingredient-Change}(container_i, Ingredient, \Delta weight_i)$

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 overhead camera captures an image which is then showed to a human observer to ask its name in the other display that the user does not see (Fig. 10). Given our time limitation, we did not implement a more practical system for identifying the type of food ingredients by family cooks, such as a voice-dialog system, a bar code reader, or a touch panel with food icons. These methods can be adopted to enable family cooks to interact with the system directly.

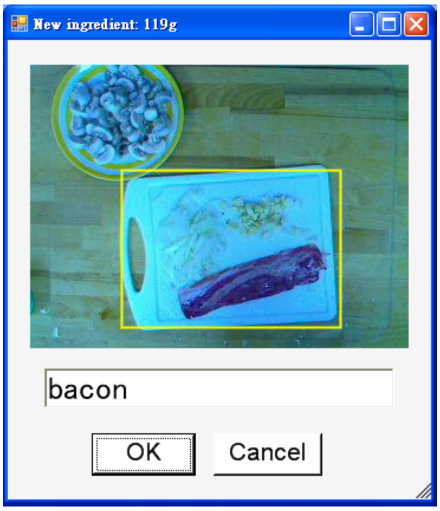


Fig. 10. Dialog window for asking input the name of new food ingredient shown to human observers.

Finally, a public nutritional database [46] that provides the nutritional values of each ingredient is used by the calorie calculator to determine the calorie count. The database stores a unit calorie count (in kcal) for each 100 gram of food ingredient. Then, by looking up this database, our system can determine the calorie count of each food ingredient given its name and weight. A high-level *Calorie-change* Event that describes ingredients and their calorie amount contained within a container, such as (“container$_1$”, “salad oil”, 130 kcal) is reported to the awareness display to interact with the user.

3.5 Commonsense Reasoning

In the cooking scenario, weight matching algorithm which only matches the amounts of weight decrease and increase is not robust and flexible enough. There are few limitations of weight matching: (1) we originally assume that the ingredients inside the same container are *mixed together*, so that for weight transference, all these ingredients are divided proportionally. For example, after the user removes the pot with 500g water and 500g noodles cooking together from the stove, system then senses 500g weight increase in a bowl, we assume that it’s 250g water and 250g noodles regardless of the possibility that almost all weight decrease comes from removed noodles due to drain of noodles. There are also similar situations, such as wrapping meat with powder (only meat and some powder will be taken; the rest of powder will be remained), and heating meat or vegetable with boiled water and then taking the ingredients away. (2) For some ingredients, only parts of them are *edible*; therefore using total weight including the inedible parts leads to incorrect calorie counting. For example, in many dishes such as “spaghetti with white clam sauce”, clams are often cooked with shells directly. If this happens in our kitchen, the system will incorrectly count the shells as flesh and provide incorrect calorie information (two to three times over). More examples are chicken legs, fish with bone, and apples with core. (3) There are some *natural principles* of cooking that may influence weight changes. For examples, boiling water or liquid on the stove produces constant water evaporation resulting in weight decrease, and noodle will absorb water when cooking together that results in weight increase.

If our system were to rely exclusively on weight matching, the accuracy could be poor, especially when the ingredients and cooking steps happened to have the above problems. One proposed solution is to ask user to manually identify every Weight-change Event, however, at the cost of annoying and interrupting the users during their busy cooking process. Therefore, *commonsense knowledge* on cooking is added to enhance the inference engine. When a weight change has potential problems described above, our system responds by showing possible conditions and asking users to confirm them. For example, when clams are added to the system, the engine then shows a dialog window for users to one-click whether the clams are with or without shells. In doing so, a balance can be achieved between users' efforts on inputs and the system inference accuracy.

3.6 Assumptions and Limitations

In order for our kitchen system to work properly, a family cook needs to follow some simple rules to interact with our kitchen system. To help system inference and to ease human labeling to identify each weight change, we restrict all ingredients to be placed inside or on top of containers, in which plates, bowls, cutting boards, etc. are also counted as containers. Second, since our tracking method is based on weight matching, the current prototype imposes two limitations: (1) whenever a user performs a cooking action that results in weight change, the user needs to wait for the system to recognize the action (i.e., a "ding" sound indicating the weight change has been detected) prior to performing the next action. (2) 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. Thus, this kitchen is mainly for single-user, i.e. there will be only one family cook to cook with the system.

3.7 Implementation and System Interfaces

The main program was implemented with the programming language C# using the programming tool Microsoft Visual Studio .NET 2005. The video analysis algorithms of camera sensing were implemented with the language Matlab for high efficiency. The connection between these two programs was created by Matlab Builder for .NET. The resolution of images is 320×240, taken by a basic web camera through a USB port.

Fig. 11 shows the user interface of our calorie tracker. This interface is for observers to monitor the sensing process. This interface shows (1) how the Weight Change Detector recognizes weight changes, filtered by camera sensing; (2) how the Ingredient Inference Engine matches weights and infers what ingredients; and (3) what values the Calorie Calculator calculates and sends to the awareness display. This user interface also shows the spatial layout of the containers and ingredients on the kitchen counter to help the observer manually fix any incorrect recognition detected by our system.

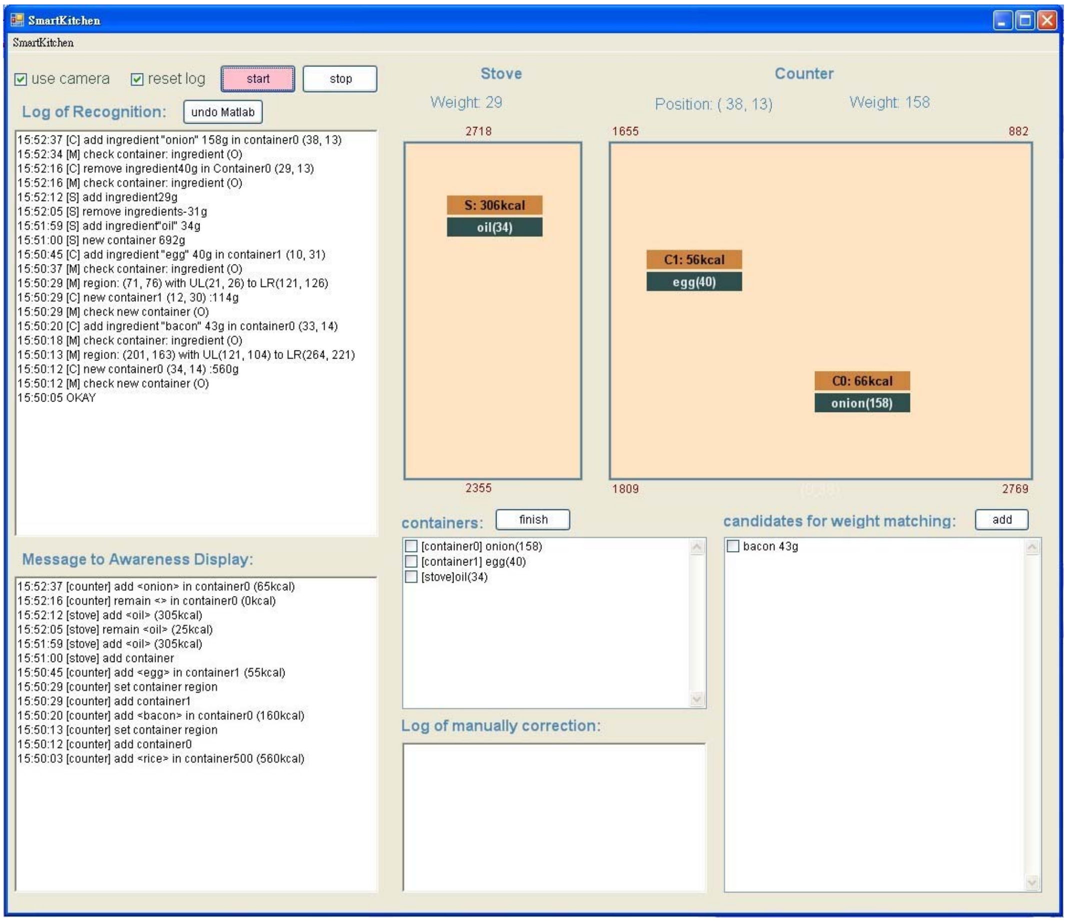


Fig. 11. System interface for observers to monitor the sensing process.

3.8 Recognition Accuracy

Recognition and tracking accuracy of ingredients is important to provide correct calorie feedbacks to users. From the three user studies described in a later section (consisting of seven participants cooking a total of 16 meals using our system), our hybrid sensing method has achieved a recall of 88%, in which the most frequent errors were caused by the weighing sensors under the stove (which does not have a camera filtering). Our current system requires the human observer to manually fix recognition error produced by our system. The recognition precision was 95%, in which the most frequent misses occurred when the weight of the food ingredient is below 1g (the resolution of our weighing sensor) and when the camera sensing incorrectly filters the weight change. To prevent recognition errors from confusing the users, our human observer immediately corrected these recognition errors.

The accuracy of the calorie measurements was 92%, which means our system-tracked calorie count differed by an average of 8% from the real (ground-truth) calorie count, which was measured by subtracting the left-over food ingredients from the starting food ingredients. Note that some errors were inevitable as the kitchen counter was embedded with 4 weighing sensors (each has an error of ±1g). For a high-calorie ingredient, even a small weight error amplified the error in calorie measurements.

For every cooking event (adding/removing ingredients), the average response time is 1 second to show calorie information on the awareness display.

Chapter 4

Awareness Display Applications and User Studies

After the calories in food ingredients have been determined by the calorie tracker, our system then provides real-time feedback to report calorie information on the awareness display in front of the user. By showing calorie information immediately after a cooking action, our system brings calorie awareness to users during their cooking process. In this section, we show three iterative designs of the awareness display: a *nutrition-fact-aware* display, a *calorie-aware* display, and a *calorie-control-aid* display with nutritional balance information, which reveals and visualizes calorie and nutritional information in different ways.

4.1 Nutrition-fact-aware Display

The first awareness display was designed to show not only calorie, but also nutrition facts on each ingredient, since different nutritional element may be relevant to different chronic diseases. For example, if a family member is diabetic, special cares should be given to prepare meals with lower fat, calorie, protein, and sodium [1]. We thought that by bringing all the detailed information to users, they could decide what information would be relevant or irrelevant to them based on their personal needs. The design of our awareness display was to inform users whenever their action resulted in a nutritional change, so that they can read the numbers and be aware of how much nutrition the ingredient contains. At the same time, the cooks can browse through the overall information of how many ingredients they have already used in the system. The application is to help family cooks make their own decisions, so that we do not constrain their preferences.

4.1.1 Interface Design

Fig. 12. User interface of Nutrition-fact-aware Display: the top figure shows the overview that user can see, and the figure in the bottom shows a closed look of information in a certain container, including the name and weight of each ingredient.

Fig. 12 (top) presents the designed user interface. The right half is an overview of information on food ingredients in the system with direct spatial mapping to the kitchen surface, including the name and weight of every ingredient in each container (Fig. 12 bottom) on the counter and stove. The left half shows not only the number of calories but also nutrition facts associated with the latest ingredient change. For examples, while a user places a piece of bacon on the kitchen counter, our kitchen immediately shows the nutritional information, including its high calorie count and saturated fat count.

4.1.2 User Study

The first awareness display was tested in a small-scaled user study. The objective was to observe how cooks reacted to the provided information and to ask them whether they found the provided information helpful to healthy cooking.

We invited one experienced household cook to participate in our smart kitchen located in our laboratory. She decided to cook "spaghetti alla carbonara" for 4 main-course servings. After the participant finished cooking, we then conducted an interview to acquire comments.

4.1.3 Result and Discussion

The participant commented that the direct spatial mapping to the kitchen surface made it easy to grasp information. However, we realized this design failed to meet some of the design considerations mentioned in Section 2.1. First, the participant commented that the nutritional information was too complex, including six nutritional elements with high decimal points. Such complex information was both too much and overwhelming for comprehension. She could not understand the importance of some of these elements and make a proper interpretation whether she over or under prepared each of the elements. Although she realized the importance of controlling calories, she did not know how much her family should take, i.e., a recommended value to compare with. Second, some information was redundant, including the weight of each ingredient. She did not need to acquire the weight counts since she measured the amounts based on her experience. Third, she could not acquire the total nutrition facts of final servings until she mixed everything and finished cooking. She could not remember how much nutrition she was already included in her dish. Last, she felt interrupted when the information over the whole left screen changed whenever she performed an action. Therefore, she strongly suggested that the design should be revised to meet the goal of promoting healthy cooking.

4.2 Calorie-aware Display

Based on the findings in the previous user study, the goal of the awareness display was revised to the most important attribute in the nutrition facts - calorie count. That is, the second prototype of the awareness display was focused on providing only calorie awareness to a family cook. Based on the design considerations learned from the first prototype, we keep the information simple (calorie only) and real-time, showing the recommended calorie count for users to compare with the calorie usage of their current cooking.

4.2.1 Interface Design

To determine the recommended number of calories for a meal, we referred to the Harris-Benedict equations that determined personal calorie daily needs based on personal weight, height, age, and the individual activity level [18][48]. The suggested calorie intakes of three meals a day are 1/5, 2/5, and 5/2 of the calorie daily needs for breakfast, lunch, and dinner respectively. Therefore, prior to using our system, users must first input the profile on their family members (shown in Fig. 13), so that our system can calculate the recommended number of calories for this family.

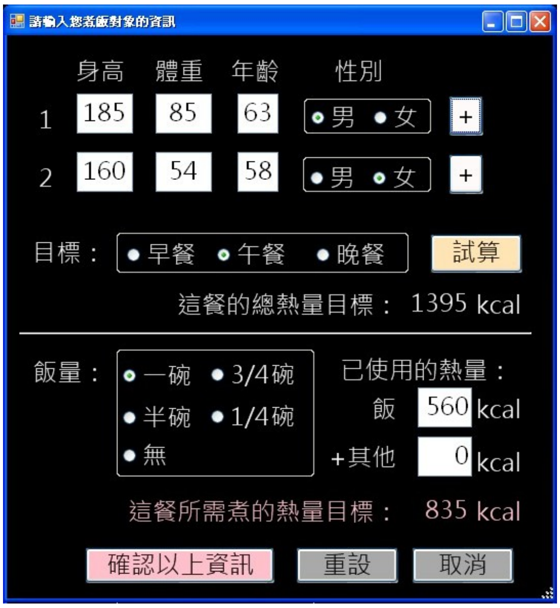


Fig. 13. Inputs of personal information for calculating user's recommended calorie level in a meal

Fig. 14 presents the revised user interface. The main part of this interface provides real-time awareness of calorie on the ingredients and dishes that mirror actual layout of the kitchen surface and actual usage and actions. It presents an overview of the number of calories in current ingredients on the stove and counter (Fig. 14(a)), to enable family cooks to obtain information efficiently. The information on containers, including the total amount of calories and the names of the ingredients in it, are displayed (Fig. 14 bottom) based on their actual spatial positions on the kitchen surface. In addition, the region of each container is determined by the actual size of the container captured by the camera (Section 3.3.2).

All changes on the interface are made with a short and simple sound to notify users.

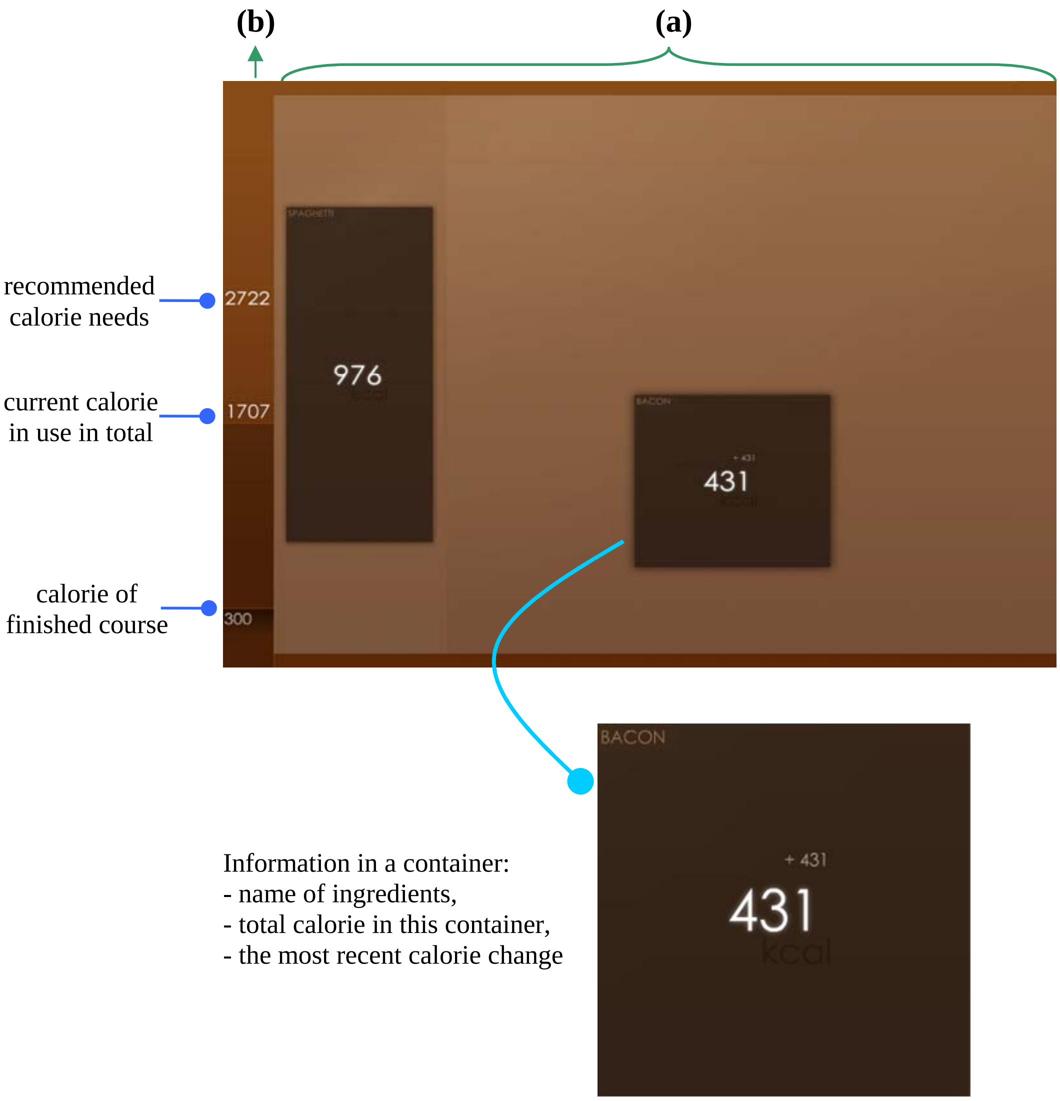


Fig. 14. User interface of Calorie-aware Display, including (a) overview of calorie in the system; (b) recommended calorie needs and current used calories

In the left part of our UI (Fig. 14(b)), a vertical bar is used to show the recommended number of calories for the meal for this family. During the cooking process, the current total calories in use are presented, to facilitate comparison for users. Additionally, when a user finishes one course and removes it from the system, the removal is recorded and the number of calories is kept in the bar to reduce users' memory load.

4.2.2 User Study

The following two questions guided this study: (1) How effective is the Calorie-aware Display in improving the family cooks' awareness on calories in food ingredients during cooking? (2) What cooking behaviors are affected by the Calorie-aware Display?

An evaluation was performed to determine how the awareness of calories during cooking 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.

4.2.2.1 Participants

Three adult participants, P1, P2 and P3 (Table 3), 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.

Table 3. Profiles of participants and their family members

Participants	**P1**	**P2**	**P3**
Age	24	58	25
Gender	Female	Female	Male
Household size	4	3	4
Profiles of the participant's family members (height/weight/age/gender)	158/53/23/F 156/55/22/F 170/80/16/M 173/70/23/M	175/63/58/M 153/54/58/F 155/44/23/F	165/62/52/M 164/54/50/F 172/50/25/M 166/52/20/F

4.2.2.2 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, where the setup and experimental layout are shown in Fig. 15. A video camcorder was used to record the participants' cooking sessions and their interactions with our system; their consent was obtained for subsequent analysis. A concern was raised on whether these participants' cooking behavior would be affected by the presence of the video camcorder (i.e., the "monitor problem" of changing behavior when being watched). Two observers were sitting on the side of the kitchen throughout all the testing sessions. Participants expressed that this effect was limited because they already had strong motivation in learning healthy cooking and the presence of video camcorder did not increase/decrease their motivation.

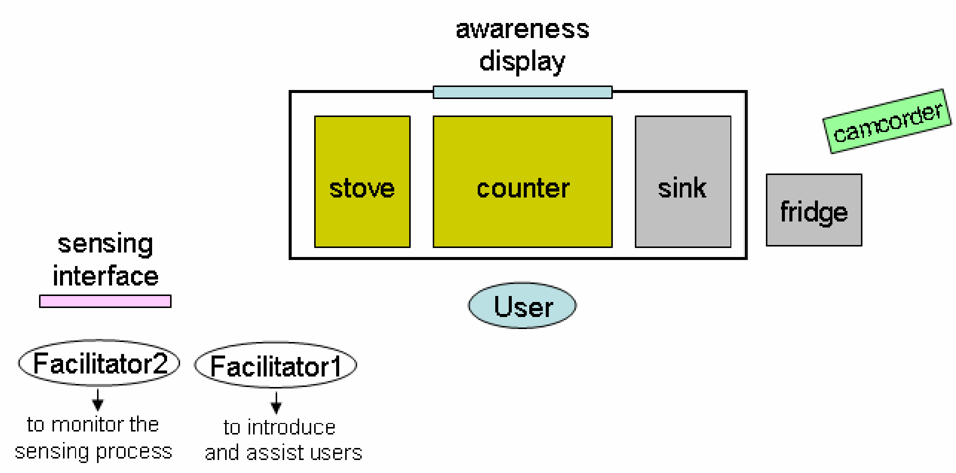


Fig. 15. The experimental setup of the user study

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 4) 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.

Table 4. Menus designed by participants for testing

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[2]); 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

[2] Campbell Soup Company. Campbell's Condensed Soup, http://www.campbellsoup.com/condensed_soups.asp (2007)

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.

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 shown in Section 3.6. Participants followed the rules 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.

4.2.2.3 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. Third, the cooking videos were analyzed and coded. The following data were recorded for each cooking session: (1) the frequency with which a participant glanced at the calorie display following a cooking action that resulted in a calorie change, and (2) the average duration of a glance at the awareness display. Finally, the posttest interview involved qualitative measurements of their understanding to ingredients and comments.

4.2.3 Results and Discussion

Table 5 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%).

Table 5. Difference between actual meal calories and recommendation (in kcal) during each cooking session.

Participants		**P1**	**P2**	**P3**
(1) Recommended calorie		2,981	1,926	2,723
(2) Pretest	Day 1	89	751	1228
	Day 2	77	715	1253
	Average	83	733	1241
	Over recommendation	2.8%	38.1%	45.6%
(3) Test	Day 3	-44	-10	585
	Day 4	-201	173	304
	Day 5	-91	-29	173
	Average	-112	45	354
	Over recommendation	-3.8%	2.3%	13.0%
(4) Reduction (PretestAVG -TestAVG)		195	688	887
Percentage		6.4%	25.9%	22.4%

We analyzed how participants changed their cooking behaviors to achieve calorie reduction. Table 6 shows the percentage reductions in calories of ingredients whose amounts were changed to reduce the overall calorie count by over 5%. 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. 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 the ingredients used in the course “Mapo Tofu” contained too many calories, so he just used smaller servings to reduce the number of calories.

Table 6. Top three reduced ingredients associated with a total calorie decrease of more than 5%

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%	butter	6.2%	oil	19.3%

Table 7 shows the results of video analysis. The first measurement yields the glancing rate, which is defined as the percentage of the times that a participant glanced at the calorie display after a calorie-changing cooking action. A high percentage indicates a strong desire to obtain calorie information. Since the purpose of the kitchen was to promote calorie awareness in users, checking whether users actually checked the calorie display while cooking is important. The glancing rate ranged from 55 to 74%. For instance, P2 was very interested in knowing the number of calories in most ingredients, especially when she put new ingredients on the kitchen surface. The second column in Table 7 lists the average glancing duration, which is defined as the average time a participant spends in glancing at the calorie display. A long average duration indicates that users take considerable time to comprehend the calorie information and then make an/no adjustment in the next cooking action. The average duration is about 2 seconds. The analysis indicates that users spent less than 1 second for low-calorie ingredients (such as garlic with 2kcal), but more time for high-calorie ingredients (such as spaghetti and oil).

Table 7. Results of video analysis

Participants	P1	P2	P3	Average
(1) Glancing rate	66.7%	74.0%	55.2%	65.3%
(2) Average glancing duration	2.75 sec	2.80 sec	1.48 sec	2.34 sec

Fig. 16 shows snapshots of how users made use of the awareness display. P1 used the calorie information to adjust the amount of spaghetti to a desirable calorie budget. Since she budgeted 1,000 kcal of spaghetti, she added spaghetti, observed the calorie count, then added more spaghetti, observed the calorie count increase, and repeated this process until the calorie count reached her target level. In contrast, P2 first poured the entire condensed soup into the pan. When she found the calorie count exceeded her target, she used the calorie display to scoop out condensed soup until her calorie target was reached. P3 checked the calorie display to reduce the amounts of tofu package.

P1 P2 P3

Fig. 16. Snapshots of how users checked the number of calories associated with adding food ingredients

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 the Calorie-aware Display: (1) in addition to maintaining calorie in a certain level, they were interested in preparing a *nutritional balanced* meal, however, nutritional balance is difficult to measure, record, and understand for them. (2) They wanted to know how to successfully reach the system-recommended calorie count. They mentioned that they became more aware of calories in food ingredients and learned how calories were gradually accumulated by cooking more courses. However, they found it difficult to properly plan calorie budget especially for later courses when they calorie budget often ran out too quickly. They commented that optimizing only the calorie count may also be undesirable at times when it conflicted with nutrition balance. (3) 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).

4.3 Calorie-control-aided Display

In the previous prototype, users expressed that they wanted to prepare nutritional balanced meals and they were interested in knowing how to reach the system-recommended calorie count. Thus, the third prototype was designed to give suggestion how to reach the system-recommended calorie count while satisfying nutritional balance.

4.3.1 Interface Design

Based on the previous user study, we designed a third application for aiding calorie control, i.e. to provide information for users to achieve their recommended calorie goal, and at the same time, to consider nutritional balance of the meal. To balance nutritional intake, the dietary guidelines of the USDA [45] introduced in Section 2.2 were used. By achieving the recommended value of each food group, family cooks can determine daily nutritional needs, while at the same time plan a nutrition-balanced meal.

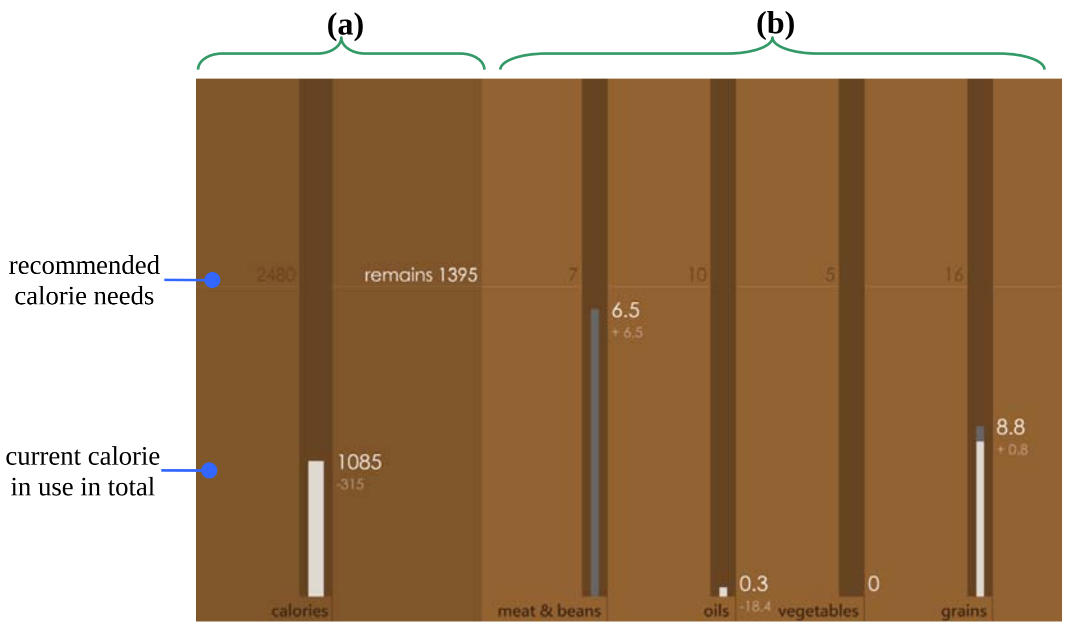


Fig. 17. User Interface of Calorie-control-aided Display, including (a) recommended calorie needs and current used calories; (b) recommended needs and current uses of the amounts of ingredients of four food groups

Fig. 17 shows the revised user interface. The interface has five bars. The leftmost bar shows current calorie usage (Fig. 17(a)), which is the same as in the previous application, Calorie-aware Display. The four bars on the right tracks the amount of ingredients used in four different food groups of meat&beans, oils, vegetables, and grains (Fig. 17(b)). There are several differences between this user interface and the previous user interface. First, the unit of ingredient is in “serving” rather than in “calorie”. Second, to reduce the cognitive load, the amount of used food ingredients are categorized into and displayed in four food groups rather than within individual containers, i.e. there is no direct mapping of the kitchen surface with each container and contained ingredients in this interface. Third, the recommended calories and food groups are calculated and displayed on the bars. Cooks can refer to the amount of each food group to achieve the recommended calories. If all food groups are within recommendations, total calories should be within recommendations as well. If the usage of a certain group exceeds recommendations, the cook may consider reducing items in other groups, 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. All ingredient and container changes on this interface are made with a short and simple sound to notify users.

4.3.2 User Study

The following two questions guided this user study: (1) How family cooks use the Calorie-control-aided Display during cooking? (2) What is the learning effectiveness of the Calorie-control-aided Display?

4.3.2.1 Participants

To ensure that the participants in this user study were highly motivated in healthy cooking, three adult participants, P1, P2 and P3 (Table 8) were recruited from a nutritional education class held at National Taiwan University Hospital. The nutritional education class from which they were recruited provided instructions 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. None of them had followed the guidelines to cook meals before.

Because P2 and P3 were couples, they requested to cook together in this user study, with one person mainly cooked, and the other assisted in preparing foods. Thus, there was no conflict of the limitation that the system is for single-user (section 3.6).

Table 8. Profiles of participants and their family members.

Participants	**P1**	**P2**	**P3**
Age	57	63	58
Gender	Female	Male	Female
Household size	2	2	
Profiles of the participant's family members (height/weight/age/gender)	155/64/57/F 160/60/26/F	185/85/63/M 160/54/58/F	

4.3.2.2 Experimental Design and Procedure

The participants were invited to cook in the laboratory once weekly for a total six sessions. As the previous user study (section 4.2.2), 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 on nutrition, (2) *test cooking* with feedback on nutrition, (3) *posttest cooking* without feedback on nutrition, 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 again determined by Harris-Benedict equations [18]. 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. This enabled us to observe different ways people considered calories while preparing different dinner menus and help us to clarify the impacts of our system. Throughout each cooking phase, the participants were given the option to refer to materials from their current nutrition class. All of them chose to prepare Chinese-style meals. After the participants finished cooking, they were allowed to bring the cooked meals home.

In the *pretest cooking* phase, participants cooked twice in two different weeks without providing feedbacks. This phase we recorded the original performance of the participants, and enabled them to become familiar with the settings and appliances of the kitchen. Participants were asked to consider calories based on what they've learned from the class. This could offer a comparison between our design and traditional education.

In the *test cooking* phase, participants cooked meals once weekly for three weeks and were given feedbacks by the Calorie-control-aided Display. 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. The participants were informed that the system would be removed in the following 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.

In the *posttest cooking* phase, participants prepared a final meal without receiving feedbacks by the awareness display.

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. No additional information about their performance other than digital feedbacks from the awareness display in the test cooking phases was provided until this phases. This was to ensure that improvement was based solely on use of the system rather than on knowledge and experience gained in previous sessions.

4.3.2.3 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. The result of used servings of the four food groups was also measured to understand their decisions on preparing nutritional balanced meals. 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.

4.3.3 Results and Discussion

Table 9 presents the difference between the recommendations and the 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) as the test cooking phase, 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.

Table 9. Difference between actual meal calories and recommendation (in kcal) during each cooking session.

Participants		**P1**	**P2&P3**
(1) Recommended calorie		820	835
(2) Pretest	Day 1	-155	182
	Day 2	123	1,168
	Average	138	675
	Over recommendation	16.8%	80.8%
(3) Test	Day 3	-123	250
	Day 4	-121	351
	Day 5	-71	560
	Average	105	387
	Over recommendation	12.8%	46.3%
(4) Posttest	Day6	49	357
	Over recommendation	6.0%	42.8%
(5) Reduction (PretestAVG -TestAVG)		89	318
Percentage		10.8%	38.1%

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 they were not sure about their usual calorie count and the calorie recommendation was higher than expected, and therefore used more food ingredients than they would use at home in order to achieve the goal based on their calculation. The inconsistent performance in the pretest cooking phase suggested that the participants were not familiar with the concept of considering calories when preparing meals.

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. One explanation for the difference is the motivation of the participants. For example, P1 expressed a strong 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. However, it was also possible that learning to prepare nutrition-balanced meals was not easy. Thus, there was no clear basis of comparison.

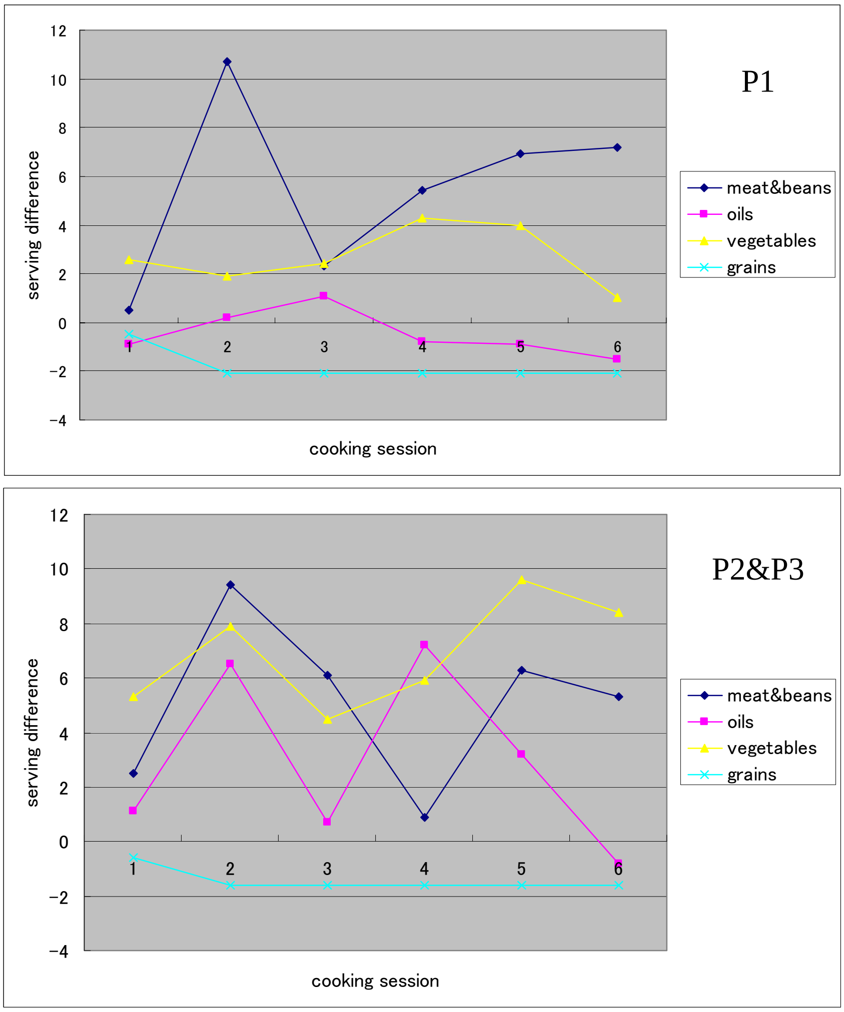


Fig. 18. P1 (top) and P2&P3 (bottom)'s differences (over or below) between actual servings used and recommended number of the four food groups for each cooking session

The results of used servings of the four food groups in their meals are shown in Fig. 18. The more stable line indicates the user was more familiar with the adjustments and nutritional balanced planning. Since all of them preferred only cooked rice as grains (3/4 to 1 bowl for each person) as Chinese-style dining habits, there was nearly no change in the grains group for all the participants. For the other three food groups, P1 has better performance (more stable lines) than P2&P3. In each cooking session, we observed that P1 was more aware of recalling her experience of measuring servings in previous meals, while P2&P3 were not. This may be one of the reasons of their different performance.

The qualitative results are described below. Participants expressed that they were more aware of considering nutrition balance in a meal, especially on the adjustments of meat&beans and oils groups. However, they were confused about balance between calorie level and nutrition balance. For example, in the nutritional class, they were told that the more vegetables in a meal the better. However, when putting on large amounts of vegetables and finding their servings were way over the recommended value at the display, users were affected and decided to decrease the amounts of vegetables, though they still believed the more vegetables the better. They explained that when looking at the changes on the bars, it was not easy to take the information just as reference.

After being explained and experiencing how to use the system, all the participants decided to separate the cooking procedure into planning food ingredients and preparing and cooking. They asked the human observers if they could at first measure the ingredients at once to achieve the recommended calorie level and nutrition balance, and then turn off the system to start to prepare and cook meals. P1 measured the ingredients by courses (measure foods for the first course, then cook, and then measure foods for the next course, and so on), while P2&P3 measured all the ingredients in the meal at once. The following reasons were derived from interviews and observations. (1) There were *too many goals* for users to achieve at the same time. When looking at such an interface, their intention was to achieve each bar (one calorie bar and four food groups) to the recommended level, although we have explained that these numbers was for them to refer to achieve the calorie value but not necessary to obey. Therefore, they decided to measure all the ingredients once, instead of observing the information in the cooking process. This system eventually worked as a tool but not to assist them in increasing awareness. (2) The *mapping between human actions and feedbacks* was not clear. When a user performed an action, what he or she saw was the transformed information instead of direct mapping. The ingredients were presented as numbers of servings in their nutritional groups, yet there were neither their names nor positions on the display. For example, when the user put on some tofu, he would found the numbers on the calorie bar (e.g. increase 140kcal) and one of the food-group bar (increase 2 servings of meat&beans) were updated. Users needed to interpret the relationships between food ingredients, calories, and servings in different groups by themselves; however, this healthy knowledge was not easy to learn. Thus, it was not easy to understand the linkage between actions and feedbacks from the display. Also users could not easily understand what actions and ingredients had been sensed or what had been missed. (3) There was *no spatial mapping* between the feedbacks and the physical infrastructure. In this way, users needed to search for the information related to the performed action among the four bars. Very often they expressed they were lack of knowledge on food categorization, e.g. tofu was in the group “meat&beans” instead of others, and thus were confused when seeing the results. The glancing time on every updated feedback was higher than the time needed using the Calorie-aware Display.

Furthermore, one problem of this user study design was that, we didn’t take their original cooking behaviors into consideration. From the pretest cooking phase, we suggested them to achieve the recommended value by all means they’ve learned. However, they explained this was different from their usual habits at home. In order to achieve the calorie goal but with limited experience of measurements, they reflected the finished courses were over their usual meal sizes. It would be better if we could collect their baseline of usual cooking behaviors, and then compare the effectiveness of the solution using technology to the traditional methods.

All the participants commented that it would be easier to learn healthy cooking and to form concepts and habits from early stage of learning cooking. One of the reasons was that the awareness might not easily lead to habitual change, especially when they have cooked for more than 30 years. Another reason is that they regarded the learning ability was affected by age. It was easier to memorize, absorb knowledge, and react in their early ages. Therefore, they suggested that this system should target on beginners to bring better and profound effects.

Chapter 5

Lessons Learned

This chapter discusses our findings and lessons learned from these three design iterations and user studies. It covers three aspects: challenges in applying technology to home cooking environment, interaction design, and healthy cooking education.

5.1 Challenges of Applying Technology to Home Cooking

5.1.1 Persuasive Technology to Family Cooks

From our user studies, we found that real-time calorie feedbacks helped family cooks *overcome the difficulties* of calculating calories in their prepared meals. Thus, our smart kitchen enabled family cooks to learn and adopt healthy cooking. We believe that the major reason for our success was that although our smart kitchen requires some additional user efforts to comply with certain system limitations, such efforts were affordable to them without significantly altering how users were cooking before. Thus, they were willing to comply and perform cook healthily. This echoes Fogg [12] that “reduction” is an important element to persuade people with computer technology. Through simplifying and reducing complex behaviors (measuring all the raw ingredients in our case) into easy-to-perform tasks (checking information on the awareness display), persuasive technology increases the benefit/cost ratio of the target behavior (cooking within proper calorie level), thus persuade users to perform the behavior. Furthermore, our smart kitchen changed their "attitudes" toward healthy cooking and subsequently influenced their decisions on food shopping, acquiring knowledge of foods, and becoming interested on healthy cooking and eating habits.

However, when designing persuasive technology for promoting healthy cooking, it is challenging to design a solution that reduces users' efforts on the target behaviors, and at the same time, imposes little or no additional efforts from users to comply with technology. In our design, the goal is to reduce the difficulties of measuring raw ingredients in a meal, and the technical solution is the weighing-sensing surface that can detect ingredients during the cooking process. However, users have to perform additional efforts, which deviate from normal cooking routine, in order to comply with our system limitations (section 3.6). We observed that some users were willing to comply in the whole cooking process, while some users decided to measure all the ingredients at once, to shorten the time to effort, which was not our initial intention. It is important to consider how various system limitations affect users' behaviors, whether these user behavioral changes are desirable or undesirable, and how to overcome these system limitations to reduce undesirable user behaviors.

5.1.2 Designing a "Smart" Kitchen

We found that integrating digital technology into a familiar, everyday activity was challenging. In order to design a smart kitchen that users can easily adapt to, the original function of a kitchen and the ways how the kitchen is used must be considered and understood thoroughly. In this study, we take the UbiComp approach of designing this smart kitchen as a *smart living object*. A smart living object is a traditional object (which commonly exists in our living environment and whose functions and uses are familiar to us) augmented with a variety of digital technology to bring about novel functions, interaction, and user experience. The "object" in this context includes not only the object with a single module, but also a thing or place with specific purposes. When UbiComp researchers experiment with new smart living objects, they are often faced with a challenging design question as to how/what to digitally augment traditional objects in a way that the *enhanced functions* are *sensible* and the *enhanced interaction* is *natural* to human. To make everyday living objects simple, intuitive, and natural to users, one suggestion is that designers should harmonize the relation between their digital enhancements and traditional uses [9]. This view is consistent with Wai *et al.* of designing persuasive technology [47] and Nielsen's usability heuristics [36]. Thus, it is important to compare the original function of kitchens and how people usually use it with our design.

First, a kitchen's original function is meal preparation, including the process of preparing and cooking ingredients. Our smart kitchen adds digital feedbacks that *complement* a kitchen's function through a display to bring calorie awareness of food ingredients to family cooks. The purpose of our smart kitchen is the same as that of an original kitchen - for meal preparation; however, our smart kitchen offers a new possibility that extends its original function from cooking to healthy cooking through the use of the awareness display. Second, the interaction of our kitchen is *intuitive* because calorie tracking is done by our system without family cooks' explicit input. Except for some small routine changes in compliance with our system limitations, family cooks basically follow their usual routines of cooking in the kitchen. In addition, family cooks can choose to read or ignore the awareness display. Therefore, our smart kitchen design provided *familiarity* to users. From user studies, we found that users easily understood the functional relationships between cooking and the calorie information provided by the smart kitchen. They also easily comprehended the interaction relationship between performing a cooking action and then checking the real-time calorie feedbacks.

We also found that applying technology for meal preparation is challenging. Food ingredients are complicated in terms of variety and purposes (such as staple foods, flavor, decoration), forms (such as solid, liquid, condense), physical properties (can be blended or not), chemical properties (melt or vaporize after heating), from different cultures (such as universal, tropical, Chinese, Western), etc. Thus, it is important to integrate "knowledge" of foods into the system for better reasoning and recognition. A knowledge-based system can be powerful especially when the system encounters complex ingredients composition.

We found that cooking involves not only habits and personal styles, but it also entails culture differences. By understanding a family cook's preference or personal style, a system can leverage this information to better tailor technology to users. However, building such a user model may be complex and require long-term observation and data collection. In our current design, human observers are needed to monitor the tracking process and correct the sensing or inference mistakes. Therefore, we cannot claim that this system works automatically without human monitoring involvement. We foresee that more interaction methods that engage users to participate in the correcting stage can be designed.

5.1.3 Conveying Design Rationale

We found that conveying how the system works and the functions of the application to users are challenging. First, since users did not easily link computing technology to a traditional kitchen, we needed to explain to users how calorie was tracked by the weighing sensors hidden under the kitchen surface and how the calorie was inferred from the weights of ingredients, etc. Thus, users could understand spatially places where sensing occurred and resulted in system output and the changes they saw.

Second, after they understood where the sensors were, it was also important to explain the *limitation* of the system. From our user studies, when we did not turn on the awareness display, the accuracy dropped down largely, due to the reasons that family cooks might often perform actions out of the rules, esp. executing concurrent actions. Therefore, it is important to convey our design rationale clearly to users, to inform them how this contained-based system can work based on weighing sensors, and let users realize the mapping between physical cooking actions and digital feedbacks from the awareness display. Our method was to demonstrate a common cooking scenario, and then let users execute to experience and remember the rules. It took about two exemplar actions in average that users learned the principle of using the system. However, some of them might still show their worries before doing actions. From the three user studies, we believe a good interaction design with mirroring feedbacks of users' physical actions may help them understand and gain confidence.

5.2 Challenges of Interaction Design

5.2.1 Designing Proper Feedbacks

In the user studies, we've found that *real-time feedbacks* were effective for users to perceive information. Users were surprised when they found the added ingredients on the kitchen surface could be immediately calculated and displayed the contained calorie. They were also surprised to know the contained calories were higher than they thought. This also motivated them to interact with the system, check the information, and consider the amounts to use.

Second, *direct spatial mapping* that maps users' physical actions with digital feedbacks was a key factor for users to interact with the system. In doing so, users can better understand how to use a system and faster grasp the information.

Third, the *affordable amounts of information* may affect their willingness to consider healthy cooking. In the Nutrition-fact-aware Display, we displayed the nutrition fact including six elements. Users could not absorb the overload information and could not consider healthy meals. In the Calorie-aware Display, we displayed calorie only. Users can solely focus on calorie adjustments within proper value. In the Calorie-control-aided Display, we provided information including calorie and food groups. To achieving all the standards, users chose to separate cooking into planning and cooking, which might be less effective to increase their awareness to healthy cooking. It was not easy to strike a balance between the richness of information and the benefits.

Forth, the information should be *easy to understand*. This may not directly correlate to the amount of provided information. For example, the information in the Calorie-control-aided Display seemed simple, with only five bars indicating calorie and four groups of foods. However, it was not easy for people to transfer the information between individual food ingredient (e.g. tofu, egg, fish, milk, and beef), contained calories, and foods groups in servings (that all the previous five ingredients were all in the same group “meat&beans”). If the information was transformed and required users’ additional cognitive load to interpret, this design might lead to a result that users used this system as a tool, instead of effectively learning the relationships between portion of ingredients and their contained calorie. Moreover, this may decrease their willingness to use the system and perform healthy cooking.

Last, the *neutral feedbacks* are sufficient to persuade users to healthy cooking. In all of our design, we chose to provide neutral feedbacks instead of positive one to encourage users or negative one to alert them. This provided flexibility for them to make their own decision. They might balance between taste and health, or redesign the menu or servings.

5.2.2 Engaging Users During Cooking Activity

A strategy in interaction design for engaging users and increasing their willingness to interact is to provide real-time feedbacks reacted and related to their physical actions. When users found their actions can be tracked and immediately reflected on the awareness display, they were willing to observe and consider the information in the cooking process, which is our goal of designing the smart kitchen, to bring awareness of their usual cooking behaviors and learn from cooking.

Moreover, the real-time feedbacks to users' actions can engage users act as participants to *monitor the tracking process* in the system. In the first and second applications, whenever users performed an action, the system showed the result of their movement with direct spatial mapping, such as putting on a container, adding, removing or transferring ingredients among containers. Since the information showed exactly what they did in the kitchen, they could easily observe the feedbacks. If there was any missing detection or incorrect sensing, users would find it and reflect to human observers immediately. However, in the third application, the information was transferred to calorie and servings, instead of showing the direct mapping of the names and positions as the cooking actions. Therefore, all the users were confused, and could not understand what had been sensed and what had been missed. Therefore, it is also important to design interactions that can acquire users' help naturally.

5.3 Challenges of Educating Healthy Cooking

5.3.1 Grading of Ability

An important element in educating health cooking is the experience of performance. In the user studies, different family cooks had different degrees of knowledge, concepts, and ability of health. Some users were more aware of calories in food ingredients, while some were not. Thus, setting a strict recommended calorie standard might not be suitable for every family cook. If some family cooks were accustomed to high calorie overuse (more than 500 kcal for example), it was more challenging for them to adjust to large calorie reduction than those who overuse by only little or even under the recommendation. Moreover, family cooks often learned from experiences and gradually gained the confidence of proper calorie control. Thus, grading becomes a necessary element in the activity design, i.e., different levels of challenges are needed for different levels of abilities. For example, for those that overuse calorie by a large amount, we may set a goal that they can achieve relatively easier. After they gain better knowledge and experience, we then adjust the goal to be closer to the recommended value. This will reduce their frustration and assist them to learn more effectively.

5.3.2 Considering Culture Differences in Cooking Behaviors

From user studies, we observed when preparing Chinese-style cuisines, family cooks tended to prepare larger servings than their actual needs. This was related to the Chinese culture that people shared common dishes on a table. It is expected that family cooks should prepare more than enough foods for family members in the case when some of them could not satiate. This increased the chances of food over-consumption while family members tried to finish the foods even when the amounts were over their needs. Moreover, due to oversized meals, there were often leftover foods which be heated in the next meals and were less healthy and fresh. Our kitchen helped family cooks become aware of this over-cooking habit; however, different habits should be considered for setting different goals for family cooks to achieve.

We found that Chinese and Western food cooking styles are different in terms of cooking methods (frying in oil, roasting, baking, steaming, etc.), speed, preparation styles, etc. Our system and user study design did not consider these cultural backgrounds differences. Although we could not claim the cultural differences lead to the different effects to users in our studies, this could be taken into consideration for future research to understand the differences.

5.3.3 Learning Effects on Experienced vs. Inexperienced Cooks

As suggested by users during the user study (Section 4.3.3), the learning effectiveness for experienced and inexperienced family cooks is different. What this implied was that it was more difficult for experienced cooks to change their cooking habits because their habits have been formed over a long time. Moreover, since learning involves users' ability to memorize, understand, analyze, plan, etc., people in early ages may have better learning performance. Therefore, the smart kitchen may be more effective for inexperienced cooks who are starting to learn cooking and may better absorb healthy knowledge.

Chapter 6

Related Work

6.1 Persuasive Technology on Health Behaviors

On the principles of designing persuasive technology, Fogg [12] introduced the concept of using computer technology as a mean of persuasion to change people's attitudes and behaviors. Wai *et al.* [47] suggested that designers should hide the goal of persuasion and behavior change by making the interactions as familiar to what users are used to as possible. Our design is consist with their principles in the way that bringing persuasion into home kitchens, which are familiar places to users. In addition, Grimes *et al.* [14] proposed a new direction of designing technology to celebrate the positive interactions that users have with foods, instead of designing technology as a "corrective" means to change undesirable human behaviors. In this way, technologies can empower users with confidence and creativity. Our current designs were to correct family cooks' healthy cooking behaviors, but our methods were to provide neutral feedbacks instead of negative one, thus users could still gain interests and confidence when they found they became more aware the calorie knowledge.

Work and commercial products have exploited mobile devices or ubiquitous computing to record personal food intake or calories, and further persuade people into healthy eating behaviors. MyFoodPhone [33] is a nutrition tracking service running on mobile phones, allowing users to send pictures of consumed foods, get feedbacks from dietitian, and share their record with the community. This provides a new method of engagement. The Diet-aware Dining Table [8] can track what and how much users eat on the dining table and then provide nutritional awareness to diners. Work from Mankoff et al. [30] tracks nutrition of foods users have taken and provides suggestions about healthier foods based on analysis of shopping receipt data. IE Institute Co. developed the “Calorie Navi” game [19] running on Nintendo DS[3] that helped user record food intake of 300 types of foods and exercise level. This assisted users in considering the choices of foods. The Playful Tray created by Lo *et al*. [29] was an enhanced food tray with a digital game to address long mealtime problem in young children. The tray used the eating action of a child as input to play a racing game. In the game, the child first selected a favorite character to race in the game. A randomly selected character moved one step forward as the system detected each child eating action. To win the game, the child must eat at an appropriate speed. These projects focused on food consumption, whereas this work focused on the food preparation by raising calorie awareness on preparing and cooking foods in home kitchens.

[3] Nintendo Co.: Nintendo DS. http://www.nintendo.com/channel/ds (2007)

6.2 Enhancement of Cooking Experience

6.2.1 Augmented Kitchens

Much research effort has focused on augmenting kitchens with digital media to create rich, interactive experiences for users cooking in a kitchen. Some work has focused on increasing awareness to *support multi-tasking* cooking activities in the kitchen. For instance, the Counter Intelligence project from MIT [4] augmented a kitchen with ambient interfaces to improve the usability of the physical environment. It assists users to determine temperatures, find things, follow recipes and time steps during meal preparation. Some focuses on *providing suggestions* based on the kitchen facilities or users' intention. Su-chef [23] considered the parameters of a cooking environment, such as the availability of ingredients, devices, or utensils, and then dynamically composed recipes through AI planning algorithms. In doing so, users did not need to worry about the lack of tools or ingredients they needed in a kitchen. Lee *et al.* proposed the KitchenSence [25], which was an infrastructure to augment appliances in a kitchen. It inferred users' attention by sensing different appliances and reasoning with commonsense. Then, the system could simplify users' attention level by helping them make relevant decision. For example, when a user opened a refrigerator and then walked to a microwave, the system inferred that the user wanted to reheat the foods taken from the fridge. Based on this inference, the system showed relevant cooking choices to reheating foods that user could choose from. The Intelligent Kitchen project [34] adopted data mining techniques to infer the next human cooking action and offered suggestion on the next cooking step through an LCD display or on a robot. There is also work that enabled family cooks to *communicate with others* during the cooking process. Ueda *et al.* [44] enhanced a kitchen by developing a home conversational robot that can help users communicate and exchange messages about their cooking experiences with their remote family members and friends. The home robot communicated with other robots in other homes through a network.

6.2.2 Augmented Recipes

There are several systems that focused on digital interactive recipes that guide users through a *step-by-step cooking process*. For examples, the Cooking Navi system [17] developed a recipe navigation system that provides just-in-time instruction with multimedia information including text, video, and audio. Such digital recipes offer a more interactive experience than a paper-based recipe book. The CounterActive project [21] used a digital functionality to teach people how to cook by projecting multimedia recipes onto a touch panel-like interactive kitchen counter. The eyeCook from Bradury *et al.* [6] provided a multi-model attentive cookbook using eye-gaze and voice commands to navigate the recipe. Such digital recipe systems provide richer interactive experience than that of a paper-based recipe book.

Several work focused on enabling users to *record and share their cooking experiences* with other people. Terrenghi *et al.* [42] presented the Living Cookbook, which enabled people to share cooking experience with others, to teach cooking lessons to others, and to foster social relations. Siio *et al.* [39] automated the creation of web-ready multimedia recipes in a kitchen. By operating a foot switch, a user *captured* images of the cooking workplace, which were annotated with voice memos, and organized a multimedia recipe.

Other work aimed to help users *read instructions or recall* recent cooking actions. Tee *et al.* created a visual recipe book with semantic model for cooking instructions [41]. A recipe was first broken down into five components: measurement, tool, action, ingredient, and duration. Then, the proposed recipe book combined visual instructions and navigational structure to help people with language disorders to cook. Cook's Collage from Tran *et al.* [43] helped users remember past cooking steps from an interruption (e.g., answering a phone) by capturing and reconstructing a visual summary of past cooking steps with images.

More work extracted traditional text-based recipes into *specific structures* such that the recipes could be enhanced with new interactive styles. Hamada *et al.* incorporated text analysis on recipes [15] and cooking video analysis [31]. By creating meaningful association between the text and video sources [16] they were able to classify every keyword in a recipe into ingredient, seasoning, single action, mix action, and place action. The Synesthetic Recipe [28] provided a graphical user interface for users to brainstorm a meal recipe by describing the taste of an imagined meal, such as mushy, moist, etc. By performing an ontology-based searching on a recipe database with commonsense reasoning, the system interactively composed a recipe with the users that produced the described taste.

Rather than augmenting kitchens with a range of digital media to create interactive cooking experiences, our smart kitchen focuses on promoting healthy cooking by raising calorie awareness during the cooking process, while leaving the decision about how to cook to the users.

6.3 Activity Recognition

6.3.1 Cooking Behavior Recognition

Several projects targeting cooking activity or food ingredient recognition are described here. Kranz *et al.* [24] developed an augmented cutting board and knife to infer the type of food being handled. Bolle *et al.* [3] developed a vision-based system that recognized different types of fruits and vegetables. The Intelligent Kitchen project [34] presented an activity recognition system that adopted data mining techniques to infer what would be the next human cooking action by observing a sequence of current user actions from reading IC tags that users touched. Morishita *et al.* [32] developed a kitchen counter with various sensors to adapt to the physical preferences of a family cook, for example, to change the height of the counter. This was achieved by identifying and recognizing relevant user context such as the user's position, preferences, intentions, etc.

Our work differs from them in tracking calories in ingredients by an augmented kitchen during the cooking process, and show real-time calorie awareness for users to perceive.

6.3.2 Recognition Using Commonsense reasoning

H. Liu *et al.* have built a commonsense knowledge base and natural-language-processing tool-kit called *ConceptNet* [27], which is automatically generated from the Open Mind Sense (OMCS) Project [40]. This knowledge base also contains commonsense of food cooking. However, since it is a general toolkit including various commonsense domains in our daily lives, the relationship about cooking is very general, e.g. cook food – is a – fun activity, cook food – do – kill bacteria, etc. They have different focus with ours, and are not applicable to our system.

D. Wyatt *et al.* also applied commonsense into activity recognition [51]. They constructed commonsense of activities of daily living from the web by first building the model of the relationship between activities and objects, and then for recognizing activities. The KitchenSence [25] described in the section 6.2.1 also applied commonsense reasoning to infer users' attention during the cooking process by sensing appliances such as opening the refrigerator or microwave. Although we share similar ideas about constructing commonsense for activity recognition, our main focus is on the specific attributes of ingredients, thus, recognition methods and structures are different.

Chapter 7

Conclusion and Future Work

The Calorie-aware Kitchen employs UbiComp technology to improve traditional meal preparation and cooking by raising awareness of calorie information in food ingredients that go into a meal. The kitchen is augmented with sensors to track ingredients and calorie changes during the cooking process, and then provides digital feedback on calories. The results of user studies suggested that providing real-time calorie awareness to users during their cooking process can be an effective mean in helping these family cooks maintain the healthy level of calories in their prepared meals.

In the near future, we would like to switch our target users from experienced family cooks to inexperience family cooks who want to learn healthy cooking knowledge in the early period of cooking career. We believe that our technology can bring more benefits to inexperience family cooks because new behaviors, yet to form into long-term habits, are easier to change and influence. In addition, we want to incorporate the element of enjoyment to the learning process, to position our system not only as a "corrective technology" but also a "celebratory technology" that brings pleasure to cooking [14].The element of enjoyment can not only enhance users' motivation to learn healthy cooking but also increase our technology acceptance at home.

For our long-term future direction, our smart kitchen will consider a broader context in its social and culture impacts of using UbiComp technology to promote healthy cooking. In this way, learning healthy cooking is not only an individual activity, but can be strengthened by a community. By sharing people's own experiences or receiving feedbacks from other family cooks, people may learn from each other. Additionally, the social aspect of technologies, as demonstrated by Wii Fit [52] and Fish'n'Steps [26], can bring stronger motivations to perform and continue healthy cooking. Furthermore, cooking should be considered as a social behavior involving both meal preparation and consumption. Our design and user study should cover not only family cooks but also feedbacks on food taste or flavor from family members as meal consumers. Thus, we would also like to build a bridge of this study on cooking with dining activity, to understand how these two sequential activities may influence each other, and how technology may be applied to raise people's healthier awareness.

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