Interactive Cooking Simulator:-showing food ingredients appearance changes in frying pan cooking

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ABSTRACT

We propose "Interactive Cooking Simulator" which provides users with information of physical and chemical reaction state during cooking process. This system helps users to understand the physical and chemical changes that occurs during cooking process using visual information. We need to experience various cooking operations and the effects of each one to understand them well. However, we cannot sense the effects of the cooking operations in real-time. e.g., temperature, cooking progress of inner foods. For example, temperature inside the food ingredients during cooking can not be seen even with thermography camera. On the other hand, the cooking simulator can simulate inside states of the food ingredients and can present it to the users. We believe that the proposed system helps user to understand cooking operation effects.

Categories and Subject Descriptors

I.6.8 [**Types of Simulation**]: Visual; I.6.3 [**SIMULATION AND MODELING**]: Aprications

General Terms

Experimentation

Keywords

Visualization, Cooking Simulation, Thermal Simulation

1. INTRODUCTION

Cooking can be defined as a series of operations to be accomplished without failing. We can enjoy delicious dishes when we cook foods well. But when we cook badly, we have to unpleasantly eat the badly cooked dish. If a person could practice cooking with essential information to understand phenomena in cooking operation, this person can understand cooking operations and ingredient chemistry deeply to apply the knowledge to their actual cooking. Thus, we propose a novel virtual cooking environment to enable practicing purposes. Our proposed system reders ingredients and a frying pan in three-dimensional computer graphics. It simulates heat transfer, shows visual changes by the ingredients, offers a thermal visualization and reflects user's operation interactively.

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2. RELATED WORKS

There are 3D animation researches and game works which show cooking process. Oowada[12] researched the way to generate stuffed CG models of foods. Takayama[15]proposed a method to express a fiber structure of foods with tensor field for texture mappings. Sakurai[13] suggested a baking pattern generation method to visualize crepe cooking using color mapping and bump mapping. Morii [9] suggested a way to calculate rice grain clusters like stir-fried rice in real-time. They regarded stir-fried rice model as Height Field and they calculated rice behavior. Cirio[1] proposed 6 DOF approach for the haptic interaction with viscous fluids. They also introduced an crepe preparation application which using Smoothed-Particle Hydrodynamics calculation model. Office Create[10] sold a Nintendo Wii game named Cooking Mama in which users can play cookery operations such as breaking eggs, mixing liquids, spreading butter on frying pan using the game controllers acceleration sensors while observing the 2D animations presented. Ootaguro[11] proposed a scented cooking game which intended to replecate spicy savor perception during curry cooking operations.

These are some researches on modeling the changes on food ingredients via cooking operations. Sakai[4] studied the denaturation speed of Japanese cattle meat using the DSC method to understand cooking mechanism through vacuum packed pouch cooking. Kawasaki [5] analyzed stir-fry cooking using Chinese type stir-frying pan called wok. They developed an environment to capture the heat condition of the wok surface and average surface temperature of the food ingredients using thermography cameras during the stir-fry cooking process. They also compared the turning up speed of average temperature of ingredients between cooking beginners and professionals.

Some of cooking simulation models are shown below. Watanabe[17] suggested a way to calculate heat transfer ratio where a mix of food ingredients is treated as one virtual object called a bulk to use its representative temperature. Umetani[16] proposed a 2D convective heat transfer flow simulation which reflects outer shape design of kettle interactively.

3. PROPOSED SYSTEM

Sauteing is one of a cooking operation. Training to saute a block of beef costs a lot, and is not very easy to learn because it requires interactive operations. Therefore, we build a system that visualizes cooking changes (e.g. temperature, protein denaturation, burns) that corresponds to the user's operations interactivitely. Then, we can examine an expressiveness of cooking changes of food ingredients.

Our target cooking is sauteed beef steaks with some vegetables. In order to practice cooking with a frying pan, the visual results should be reflected to the user's operation in realtime. In our proposed system, the motion of the frying pan is inputted as the cooking operation. The reactions are shown as change of appearance, such as the motion, heat transfer, and burnt conditions on the ingredients. Moreover, we think it will be more intuitively to perform inputs using force feedback from the weight of the foods on the frying pan as colliding impluses. Hence we make addition force feedback to proposed system.

The cooking simulator consists of these elements. (A)Haptic Interface, (B)Realtime Dynamical Simulation, (C)Realtime Thermal Conductive Simulation, (D)Realtime Simulation of Cooking Changes on Food Ingredients, (E)Graphics Rendering for Visualizing, (F)Image Display System

3.1 (A) Haptic Interface

We use SPIDAR-G(Sato[6]) based haptic interface system attached to a real frying pan as the grip of the haptic interface. Users can operate the frying pan and input operations of 6 DOF translation and rotation.

We design a new string connecting point to the frying pan and motor locations. We put these motors under the frying pan because the motors only need to pull the frying pan downwards during the cooking operations. 8 strings are connected under the frying pan and 4 couples of motors are located besides the frying pan(forward, backward, left, right sides). A CG frying pan is syncronized to the real frying pan's motion. When some food ingredients are on the virtual frying pan, the haptic interface gives force feedbacks to the real frying pan. For example, the weight of foods and collisions between foods and inner surface of the frying pan are feedbacked to the real frying pan using the motors by pulling through the strings. We also prepared a cooking turner handling grip in addition to frying pan. The cooking turner has also 6 DOF but no force feedback. We can operate the frying pan and the cooking turner using both hands. Also we also developped an easy flipping foods function on the keyboard.

3.2 (B) Realtime Dynamical Simulation

For dynamical simulation we use a physics engine called "Springhead2" developped by Hasegawa[3]. In this engine, the food and the frying pan are presented using rigid convex meshes and collisions between them(Fig.1).

3.3 (C) Realtime Thermal Conductive Simulation

The dominant differential equation of heat conduction is derivartion from the Fourier's law;

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial Q}{\partial t} + \lambda \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \qquad (1)$$

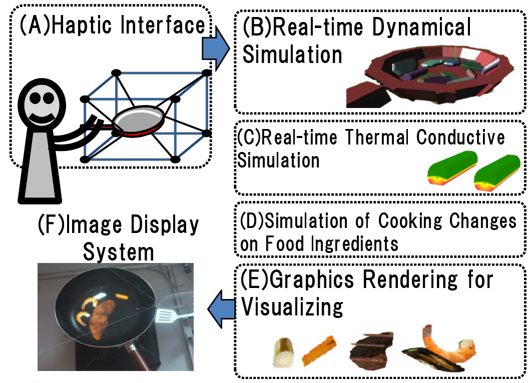

Figure 1: Elements of the system requirements

where $T[K]$ is temperature of the vertices meshes, $\lambda[W/(m \cdot K)]$ is the thermal conductivity coefficient, $c[W/(kg \cdot K \cdot s)]$ is the specific heat and $\rho[kg/m^3]$ is the density. We regard thermal conductivity coefficient as homogenous and isotropic value. We made derivation equation using the Finite Element Method by dispersing the heat conduction onto spatial and time. In usual Finite Element Method, a shape function is used to calculate the relationships of mesh vertices. We do not use the shape function but we regard the relationships of vertices as 1 dimension line segments which consists of cubic clusters. Therefore, the cross section of the cubic cluster is calculated using the cubic edge length. Thus, the heat conduction simulation requires some restrictions such as uniformity of vertices and edge connections.

We applied the thermal conductivity simulation only for the food inside. We use thermal conduction ratio and heat specific values references from books[14].

For the heat transfer from the frying pan to the foods, the simulator changes the temperatures of the food mesh vertices whose distance from the surface of the frying pan are within a decided threshold.

3.4 (D) Simulation of Cooking Changes on Food Ingredients

The system calculates water evaporation amount depending on the temperature. If one vertex's temperature reaches the boiling point, the evaporation of the water takes the latent heat out from the vertex. It assumes that all of the difference of node temperature and boiling point were absorbed by latent heat. The amount of evaporation is calculated using temperature differences.

In order to simulate foods which contains a lot of protein, the system utilizes proteinic denaturation simulation. We developed a denaturation simulation for beef steaks and shrimp.

The fatty parts of meat has a small thermal conductivity coefficient than lean tissue parts. The same theory is applyed to sirloin steak which is used for this simulation.

The system applies browning according to the evaporation calculation results. The Maillard reaction, caramelizing and carbonization are the factors for browning. We cannot distinguish these reactions, because these factors are concurrent reactions that happen in temperatures more than 150 °C. Therefore, the system begins browning simulation from temperatures above 150 °C.

3.5 (E) Graphics Rendering for Visualizing

We propose a graphics rendering technique to express temperature changes, moisture evaporations, protein denaturation and browning by thermal conduction. We can apply depth coordinates to texture on mesh vertex in addition to plane coordinates by using the Three-Dimensional Texture Function of OpenGL. When the burning condition or the heat conduction or the protein denaturation of the food vertex progressed, the deeper the coordinates of texture is applied. For example, when we cook a beef steak in our simulator, the first applied texture is a raw condition texture. After raw texture, such as protein denaturation stopover texture, after the denaturation texture, the burnt texture will be applied. We also prepared a burnt texture for the vegetables. We did cooking experiments for capturing the burnt vegetables texture. From the results, we applied the burnt textures as water decreasing results. If texture the depths are different at both endpoints of one mesh side, intermediate texture pixels between endpoints are mixed.

For showing the temperature of vertices, we prepare 7 colored textures which represents temperatures between -50 to 250 °C. We prepared 2 texture images, before and after for denaturation of the shrimp. We also prepared 2 sets of texture images for the beef steaks. One is for the marbled steak, and the other one is for the lean steak. We classify beef steak textures into 3 groups. The first condition is raw, the second one is under denaturation and the last one is under browning. If the denaturation of chromoprotein myoglobin progresses, the beef color changes from red to brown. The color of myoglobin changes from red to pink at temperatures at 65 °C and becomes brownish-red at 75 °C or more[2]. Hence, in our system, we regard the color changes of the beef steak as color changes of the myoglobin. Our simulator renders the browning of beef steaks, leeks and carrots. We prepare 4 browning texture images for each food with addition to raw the texture image each. We obtained the denaturation and the browning texture images from cooking experiments. The browning texture image are corresponds to the reduction of weight in foods. Especially, we regard the decreasing food weight as loss of moisture in the cooking experiments.

We prepared a system that enables user to observe both the cooked surface appearence and crosssection of the real beef steak. In actual cooking, we cannot observe the cross section of a real beef steak without cutting it open in half. However, using our system, we enable the users to observe the possible cross section of the real beef steak during cooking.

3.6 (F) Image Display System

The results of the graphic renderings are projected onto the screen using a short focus lens projector which is attached above the half mirror. Projected images on the screen are reflected onto the surface of the half-mirror. When the users look through the half-mirror, they will perceive the food ingredients image as if it was on the actual surface of the frying pan(Fig.1). The food ingridient image on the frying pan move correspondingly to the motion of actual frying pan.(left side of Fig.2).

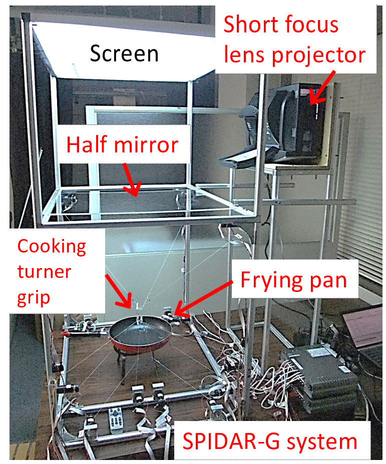

Figure 2: Overview of the interactive cooking experience system

Table 1: Equipment for the interactive cooking experience system

Personal Computer	CPU:Corei7 860 2.8GHz RAM:8GB OS:$Windows$7 GPU:GeForce GTS250
Short focus lens projector:	NEC WT610
Screen	40 inchs
Half mirror	acrylic board
Frying-pan:	diometor:26cm highest of inner edge5.4cm
Haptic Interface	SPIDARG with frying pan

4. EVALUATION

To evaluate the proposal, we made an experimental system (Table1) and evaluate the computation time and the appearance of food changes. In the experimental system we modeled beef steaks, shrimp, carrot and leek. Table 2 shows the size of mesh vertices for each food ingredients models. In the table, MBS means Marbled Beef Steak and LBS means Lean Beef Steak. Fig.3 shows the appearances and mesh of the food ingredients.

We checked if the calculation speed is fast enough to represent the experiences during cooking operation. We also checked whether the appearance of protein denaturation and browning is enough in our simulations.

4.1 Evaluation of Computation Speed

We used a simulation speed scale CPS (Cycles per Second) for the evaluation of speed. We checked the CPS during cooking some carrots (smallest number of vertices) and some shrimps (largest number of vertices). Fig.3 and Fig.4 show the result of the CPS experiments. Both calculation speed using 11 carrots or 11 shrimps are over 116[CPS]. For

Table 2: Size of mesh vertices

Food Ingredients	carrot	shrimp	leek	MBS	LBS
Size of vertices	54	119	85	1207	840

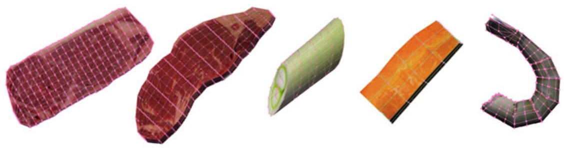

Figure 3: 3D meshed foods. Left beef steak is marbled beef steak. Right one is lean beef steak.

Table 3: Simulation speed (CPS) when carrots or shrimps are cooked

food \number of pieces	5	10	15	20
carrot [CPS]	310	205	155	127
shrimp [CPS]	310	190	145	110

35 sauteed shrimps, the calculation speed is over 60[CPS]. Therefore, the calculation speed is enough to enable vegetable saute.

The operation of the frying pan hardly affects the result of the calculation speed. Hence, the computation speed experiments were measured without applying operations to the frying pan.

4.2 Evaluation of Appearance

For the appearance evaluation, we compared simulated image results to the actual cooked pictures. We show the results of beef appearance during steaks sauteing. After that we also show the results of vegetables.

Fig.4 shows the actual result and Fig.5 shows the simulation result. These figures show the sauteing progress at a cross section which is heated from one side. Both result of Fig.4 and Fig.5 shows similar results of protein denaturation which was sauteed from one side only. For the results, we can observe and achieved the expression of protein denaturation sauteed from one side. Fig.6 is actual result, and Fig.7 is the simulation results. These figures show the sauteing progress at a cross section of the cooked beef steak after flipping steak upside down after sauteing one side.

Both results of Fig.4 and Fig.5 shows similar results of protein denaturation. From the results, we have achieved the expression of protein denaturation sauteed from both side.

Fig.8 shows the results of medium cooked steak temperature and protein denaturation.

Thermal conductivity coefficient of the lean beef steak is larger than that of the marbled beef steak. Fig.9 is the result of the lean beef and the marbled steak. The results above shows that proposed system achieved visualization of the protein denaturation from the simulation.

We experimented α) foods saute in the frying pan without operating, β) foods saute in frying pan with operation or flip overs. Fig.10 shows the results of appearance of carrots, shrimps and leeks. For the heating for the one side, we cannot check the bottom side of the foods ingredient. So we flip the ingredients upside down for the 3rd image. From these image results, we can observe that at the bottom surface of the ingredients, there are shrimp protein denaturation, browning of carrots and leeks. These changes do not appear on the upper surface.

Table 4: Simulation speed (CPS) when both carrots and shrimps are cooked

carrot	1	3	5	7	9	11
shrimp	1	3	5	7	9	11
CPS	333	293	200	161	139	116

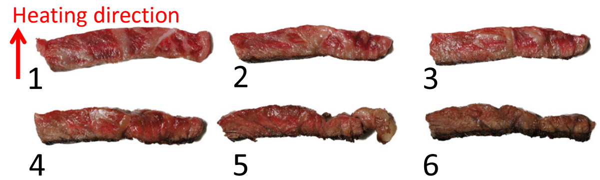

Figure 4: Unflipped steak: actual cooking cross section results of the beef steak

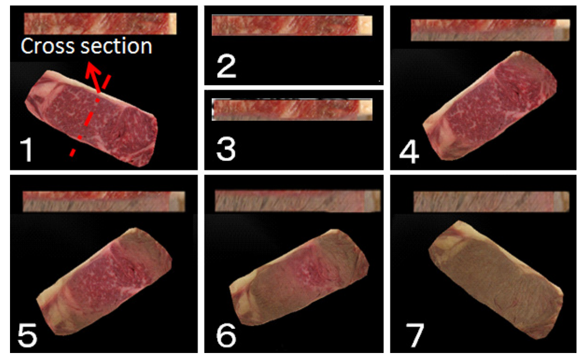

Figure 5: Sauteed simulation results from one side without flipping

Fig.11 shows the comparison for the real cooking result of carrots, leeks and shrimps cooking to the simulated ones. There are resembles in browning for the results in Fig.11. We can observe that both raw parts and browning parts are in one mesh.

4.3 User Experience Effect

Two participants participated in the experiments for determining the effectiveness of the simulator. They did not have much experiences about a beef steak cooking. We checked using a real beef steak for cooking results, before and after using the simulator.

The experiments task is to cook a beef steak medium condition, which involves cooking more than 40% of the meat's cross section area. case A) We told the user to cook the beef steak using the simulator at first. Then we told the user to cook in real for 2 times more. case B) Difference from case A is that we told the user to use the simulator

Figure 6: Flipped steak: actual cooking cross section results of the beef steak

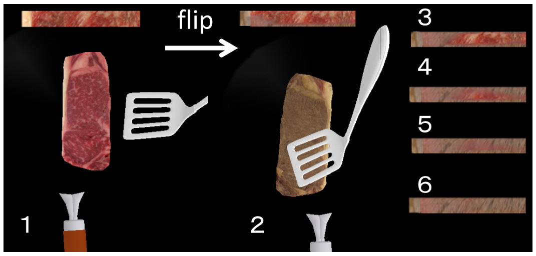

Figure 7: Cross section browning simulation results of flipped steak upside down between 1st and 2nd picture.

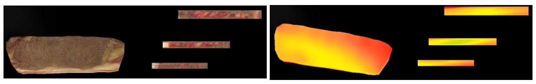

Figure 8: Left side of left image : overall steak temperature. Right side of left image:cross section temperature. Right image :same timing image of browning.

between the 2 times cooking in real. The steak mesh model vertices are divided in 5 layers. The participants can decide cooking by 60% vertices when they cook the surface in well-done. To cook the beef steak, we made up induction heating power switches which consists from power-off, low power(400[W]), middle(1100[W]), high(2000[W]) and cooling (using wet cloth for room temperature). In simulator experiments process, we show the additional information about raw meat(less than 50°C), rareness(50 to 60°C), medium(60 to 70°C) and well-done(more than 70 °C) area percentage for judging cooking progress[7]. For fast learning, we set the simulation time as 5 times faster than real time. In real cooking, the participants used a frying pan which indicates the temperature of its bottom surface. We gathered the participants subjective questionnaire both after they used the simulator and did cooking. We also printed out a medium cooked recipe which is available on the internet. We choosed a easy recipe as possible for beginners ($http://www.aussiebeef.jp/b2c/gourmet/steak/index.html$). Before experiments, we also prepared a medium-cooked beef for showing the cross section as an example.

Both participants found a medium-cooked beef method from the simulator for less than an hour (case A : 44 $minutes$, case B : 21 $minutes$). In case A, medium area expanded after 2nd sauteed. In case B, the medium cross section area decreased for the second cooking compared to the first real

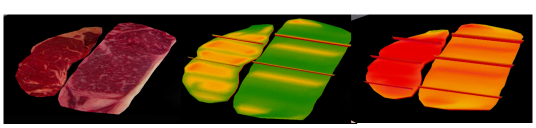

Figure 9: Left beef: lean beef steak, Right beef: marbled beef steak. Left image is the appearence before grilling. Center is the short time passed from grilling starting. The right image shows the thermal conductive differences. Red shows high temperature while green is lower temperature.

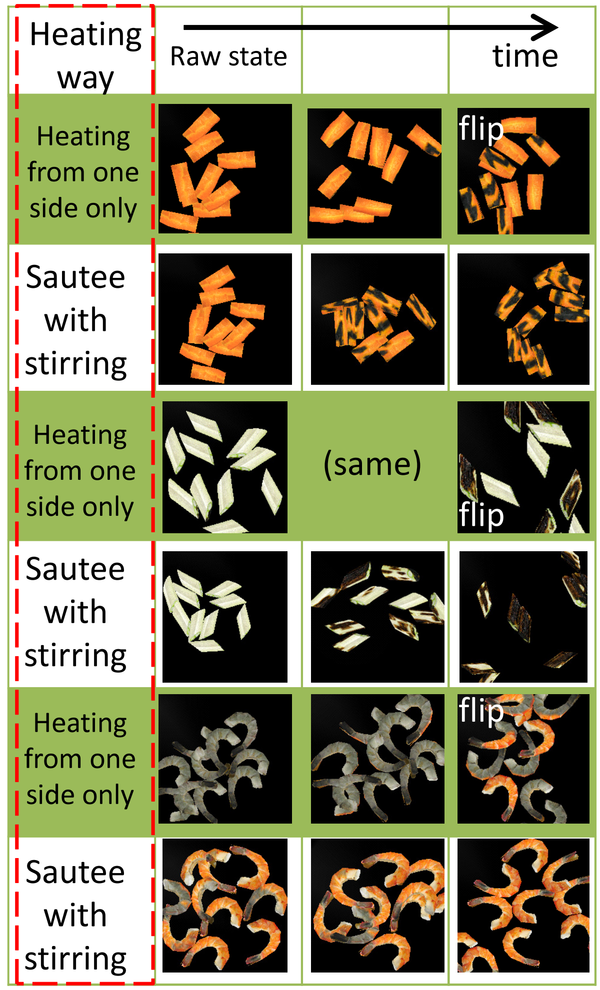

Figure 10: The appearance results of carrots, shrimps and leeks.

cooking. From both participant questionnaire results, this was because they could not cool down frying-pan as they did in simulator. Because the case B participant kept the frying-pan temperature high , his second medium area ratio for the cross section became bad. Although it was my sensory rating, in case B, the second cooked beef was juicier than the first sauteed beef.

5. CONCLUSION

In this paper, we proposed an interactive sauteed cooking simulator which visualizes cooking states (e.g. temperature changes, protein denaturation, browning from burns) of the beef steak appearence and cross sections. Our simulator can express realistic enough cooking states for visuals. These are applicable for ingredients such as carrots, shrimps and leeks. We developed vegetables burning process using visual changes with water decrease simulation. It is because both raw parts and browning parts are mixed in one mesh. Futhermore, propose simulation calculating speed is high enough to enable interactive cooking operations.

From the user experience results, using proposed system could make users improve their medium-cooked beef cooking

Figure 11: Left image: actual cooking result of carrots, leeks and shrimps, Right image: simulation result of stir-frying.

way in simulator. In case B results, the participant cooked over medium condition. It was because we set frying-pan cool simulation in a moment as wet cloth cooling function. In real cooking, cooling down frying-pan takes much longer than in the simulator. This was written in the participants questionnaires. They also wrote that they could not notice that the temperature of frying-pan was high. In case B participants experiments, the second beef was juicier than first sauteed results. Those are not statistical results, more experiments are needed. Through these results, our proposed system could help users understand cooking especially in simulation.

6. LIMITATIONS AND FUTURE WORK

The participants also wrote that they could not use the same sauteed timing as they did in the simulation. Because thermal simulation calculation were inaccurate, the participants could not use the simulated time path results especially. It was because our proposed system do not calculate the shape functions which is used in usual FEM. Improving simulation accuracy is also the next step in improving our system.

It was difficult for participants to judge when cooking has finished in the real cooking. They said that they could easily judge the cooking-time using the medium-cooked beef ratio from the simulator. From their questionnaire, we also thought that presenting hardness also could be a good indicater to judge the finished time.

In our protein denaturation model, the myofibrillar proteins, myosin and actin which are related to ingredients taste texture are not considered. For time sensitive simulations, accurate protein denaturation speed have to be considered.

Some recipes[8] said cooking sound from beef is good choice to judge heat power. The recipes also said that beef weight changes after cooking is one evidence to judge cooking finished. We would like to grope way to presenting real sound and weight changes which is usable in real cooking.

Thus those are next step action assignment. The statements above are the goals for the next step of our research.

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